VOL. 9 No. 6, p. 161-192 1947

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

A 48-CHANNEL CARRIER TELEPHONE SYSTEM

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The carrier telephone cables laid in the Netherlands since 1935 have proved to be suitable, as regards attenuation and cross-talk, for the transmission of frequencies up to about 200 kc/s with a repeater spacing of 25 km. In order to take full advantage of this possibility, the Dutch P.T.T. and Philips have together developed a 48-channel carrier telephone system. Modulation is in three stages. In the first stage all channels are modulated with a "terminal" carrier of 60 kc/s, the undesired modulation products being suppressed by a universal channel band filter. In the second stage of modulation groups of 12 basic channels are assembled by channel carriers of 192, 196. . . . 236 kc/s to form a basic group in the frequency band 252-300 kc/s, which requires only very simple filtering. By a third modulation with four basic carriers (240, 360, 408 and 456 kc/s) the four basic groups are brought into their places in the super-group 12-204 kc/s. The reasons for the choice of this method of modulation are fully discussed in this article. In the construction of the universal channel band filter operating at 60 kc/s use has been made of "Ferroxcube", the new magnetic core material produced by Philips, with which it has been possible not only to satisfy filter design requirements (the coils of the filter in question have a Q value of 500-600) but also to reduce the volume of the coils by a factor of 5. The influence of this new filter technique on the mechanical construction of the system will be discussed in another article.

The Development of Carrier Telephony

In long-distance telephone communications the line costs constitute a considerable portion of the total cost. Consequently it has long been the aim to obtain a number of telephone circuits from each physical circuit. The first practical applications of carrier telephony for this purpose were made possible in the period 1912-1920 with the advent of the three-electrode valve (triode). At that time open wire lines were used and were found to be capable of carrying three or more single side-band carrier channels. Between 1920 and 1930 this technique was extensively applied in various countries - particularly the U.S.A. where large networks of open wire lines were available.

Shortly after 1930 carrier telephony was also applied to multi-conductor telephone cables, it having been found possible to transmit wide frequency bands with a suitable repeater spacing. At first 12-channel systems were employed in the U.S.A., and later also in Europe. A frequency band of 4 kc/s was reserved for each channel and the highest frequency transmitted was 60 kc/s. In the U.S.A. existing cables were first adapted for this system (*i.e.* by removing the loading) but in Europe, in practically all cases, new cables were made and laid. In course of time, with wider knowledge and gradually improved technique in cable-making, it became evident that frequencies much higher than 60 kc/s and even up to 200 kc/s could be transmitted. [1]) As a consequence the carrier telephone cables laid extensively in Holland since 1935 allow nearly 50 unidirectional channels to be obtained on each pair (separate "go" and "return" cables are used).

About 1937-1938 carrier telephone systems on co-axial cables were introduced in the U.S.A. and Great Britain; these cables may be used up to at least 3 Mc/s., thus making it possible

*) Of the Netherlands P.T.T.

[1]) G. H. Bast. On the application of carrier telephony in the Netherlands Telephone System, T. Ned. Radiogenootschap, **9**, 279-293, 1941/42.

to obtain several hundred channels from a single co-axial circuit.

Let us consider the influence of circuit length upon the economic application of carrier working. As already mentioned, the cost of a physical circuit is high; in carrier systems the line cost per channel is the cost of the physical circuit divided by the number of channels obtained over it. Assuming that this division of the line cost more than outweighs the cost of the extra repeater stations necessary for carrier working, it follows that there is no upper limit to the length of circuit over which carrier working is economical. However, the reduction in the line charges per channel has first to offset the cost of the carrier terminal apparatus. The relative cost of the terminal apparatus increases as the length of circuit is reduced, so that in principle there is a minimum length below which carrier telephony is not justified from the economic point of view. With the gradual advance in technique the cost of the terminal apparatus tends to decrease, so that carrier telephony becomes justified for shorter distances; this is rather important because the distribution of traffic, as a function of distance, shows that there is a preponderance of short haul circuits, and if carrier working is economically possible at shorter distances it will lead in turn to mass production of carrier apparatus and a further reduction of cost. The reaction of the number of channels required on the basic cost of carrier terminal apparatus makes it very difficult to say definitely where the economic limit lies. It may be said, however, that generally speaking voice frequency circuits with repeaters are no longer justified, since as a rule carrier telephony proves more economical. On the other hand, for distances that can be bridged with audio-frequency telephony without repeaters this is, as a rule, less expensive.

Carrier Telephony in the Netherlands

Just before the outbreak of the last world war the Netherlands had reached a stage where the application of carrier telephony was to be expected on an unprecedented scale. The introduction of subscriber-to-subscriber dialling on a national basis has tended to increase the number of channels required and has added impetus to the development. The ravages of war, destruction and arrears have made the need for expansion greater than ever and the case for carrier telephony even more favourable. Some figures regarding the telephone network in the Netherlands will give an idea of the position as it was at the beginning of the war. The country is divided into 20 districts, each with a district telephone exchange through which traffic with other districts is passed. The network interconnecting these 20 district exchanges is called the inter-district network. When about 1940/41 the war put an end to the expansion that was steadily taking place, there were about 1500 carrier telephone circuits in this inter-district network with an average length of about 100 km. per circuit. The cable system carrying these 1500 channels is shown in *fig. 1.*

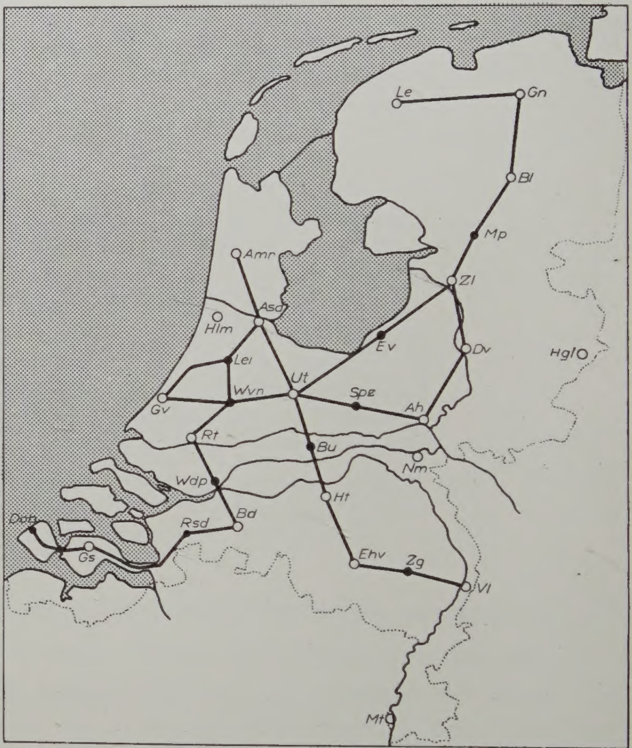

Fig. 1. The Netherlands telephone network is divided into 20 districts. The 20 district exchanges are interconnected by inter-district networks (indicated by open circles). This map shows the carrier inter-district links as used about 1940/41. The dots represent repeater stations.

The audio-frequency inter-district circuits also numbered about 1500 at that time, so that the point had just been reached where the number of carrier channels was beginning to overtake that of audio-frequency channels.

At that stage a total of about 1000 Km. of carrier cable network had already been laid. Each cable route, as already mentioned, comprised two separate cables containing "go" and "return" circuits respectively. Each cable has 24 pairs of conductors, so that by fully equipping all cables with 12 channels per pair of conductors it was then already possible to obtain (1000 ×

24 × 12) : 100 = 2880 channels of 100 km. in length. Expansion to systems with 24 or 48 channels per pair of conductors would have provided 5,760 or 11,520 channels respectively on the cable network already laid.

The prospect of such a development as this and the threat of large scale destruction during the war led to close cooperation between the Dutch P.T.T. and Philips, so as to be prepared in good time for speedy rehabilitation and further expansion. As a result a new carrier telephone system with 48 channels was developed, making full use of the possibilities of transmission over modern carrier cables. In its general set-up this system has been brought into line, on the most important points, with international standards for carrier systems.

The fundamental elements and most important details of this new carrier system will be described in a series of articles to be published in this Review. Among other things we shall deal with new constructional methods that have been made possible by using "Ferroxcube"[2]) filters. The present article will deal mainly with the basic principles of the system and in particular with the choice of the method of modulation.

The choice of a 48-channel system

Reference has already been made to the possible influence of repeater costs on carrier systems. In the relevant frequency range the attenuation of carrier cables increases as the square root of the frequency.

As the maximum gain of a repeater has already been fixed by international agreement on the basis of the maximum and minimum transmission levels permitted, the upper limit of the frequency band transmitted determines the repeater spacing. The position of the junction centres in the Netherlands network was such that the repeater spacing could be conveniently standardized at about 25 km., a distance allowing the transmission of a frequency band up to about 200 kc/s. This introduces no difficult equalization problems[3]).

But the highest frequency transmitted is also limited by far-end cross-talk caused by mutual inductance and capacity unbalance between pairs. The effect of these unbalances increases with frequency. By careful manufacturing methods, however, and by special splicing procedure described elsewhere[4]) it was found possible to make the cable suitable for the transmission of frequencies up to about 200 kc/s. Such a frequency band provides about 50 channels each with a bandwidth of 4 kc/s. With large numbers of channels it is usual to divide them into groups of 12, so that in our case we have a system of 4 groups of 12, thus a total of 48 channels.

We shall now first describe in detail the method of modulation employed and then deal with the considerations that led to the choice of this method.

Method of modulation used in the 48-channel system

The 48 audio-frequency channels are brought into the frequency band 12-204 kc/s by means of three stages of modulation.

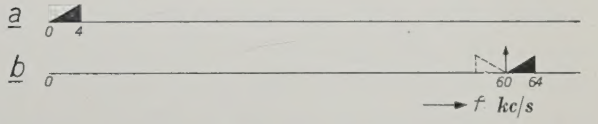

Fig. 2. Terminal modulation in the 48-chanel system. By modulating the audio-frequency channel (*a*) with a terminal carrier of 60 kc/s a basic channel (*b*) of 60-64 kc/s is obtained which is identical for all 48 channels.
In this and all other modulation diagrams given in this article a carrier is indicated by an upright arrow, a wanted side band by a solid triangle and unwanted side band by a dotted triangle. The slope of the hypothenuse of the triangle (or of one side of the trapezium in other diagrams) represents the directions of increasing audio-frequency (or, in more general terms, of the modulation frequency).

In the first stage *(fig. 2)* each channel is modulated with a terminal carrier having the same frequency for all channels, *viz.* 60 kc/s. The carrier is suppressed in the balanced modulator, as is usual in carrier telephony, and the channel band filter (which is identical for all channels) selects the upper side band of 60-64 kc/s. In this way we now have 48 basic channels occupying the 60-64 kc/s frequency band.

In the second modulating stage (*fig. 3)* twelve of these basic channels are modulated with twelve different channel carriers of 192, 196......236 kc/s. The upper side bands thus appear on the busbars to which the channel modulators are connected as a basic group of 252-300 kc/s. The channel carrier leaks and the undesired lower side bands lying between 128 and 176 kc/s are suppressed by a common band filter. Three other groups

[2]) J. L. Snoek, Non-metallic magnetic material for high frequencies, Philips Technical Review 8, 359-360, December 1946.

[3]) See for example H. van de Weg, The equalization of telephone cables, Philips Technical Review, 7, 184-191, 1942.

[4]) See article quoted in footnote1).

of twelve basic channels are dealt with in the same way, each having twelve channel carriers of the same frequencies (192 . . . 236 kc/s) and with an identical group band filter. We have

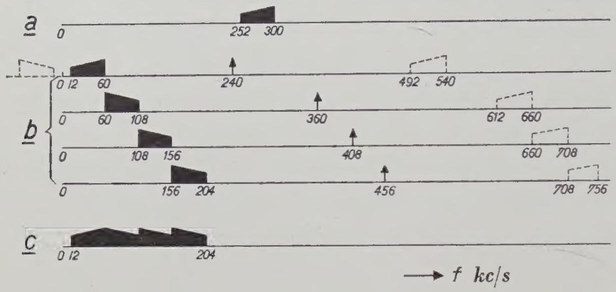

Fig. 3. Channel modulation in the 48-channel system. Twelve basic channels (a) (f = 60 - 64 kc/s) are assembled to form a basic groep (c) (252-300 kc/s) by modulating each basic channel with one of the twelve channel carriers of 192, 196.....236 kc/s (b).

thus obtained four basic groups all in the frequency band 252-300 kc/s.

In the third modulating stage (*fig. 4*) the four basic groups are modulated with four group carriers and are thus assembled to form a 12-204 kc/s super-group. These group carriers have frequencies

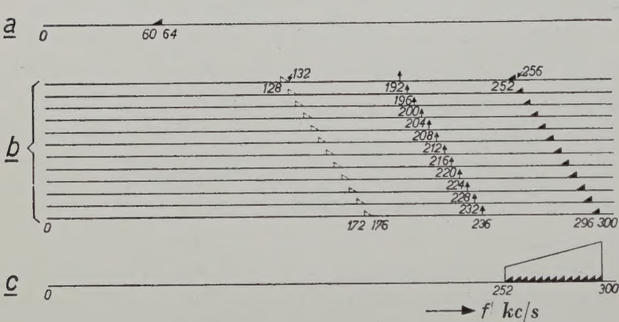

Fig. 4. Group modulation in the 48-channel system. By means of four group carriers of 240, 360, 408 and 456 kc/s. (b) the four basic-groups (a) of 252-300 kc/s are assembled in a super-group of 12-204 kc/s. (c). (The formation of a super-group is only partially shown.)

of 240, 360, 408 and 456 kc/s. The four groups occupy the 12-60, 60-108, 108-156 and 156-204 Kc/s. bands respectively and can now be transmitted on one pair of conductors. As indicated in fig. 4, the channels in the 12-60 kc/s group are erect and the rest are inverted. This is accomplished by selecting the upper side band after group modulation in the former case and the lower side band in the latter [5]).

Fig. 5 gives the frequency allocation of the whole of the modulation system; the block diagram in *fig. 6* shows the general arrangement of the carrier terminal equipment.

Before giving the reasons for this apparently complicated method of modulation it must be explained that the particular choice of upper or lower side bands was determined by the desire to conform with the recommendations of the C.C.I.F.(Comité Consultatif International Téléphonique) [6]). One of the objects aimed at in the design was to treat all channels as far as possible in exactly the same way in order to make the equipment interchangeable. The terminal carrier is identical for all 48 channels, as is also the channel band filter. The group band filters and the channel carriers are likewise identical for all four groups.

[5]) An erect channel is one in which the highest channel frequencies correspond to the highest frequencies q of the speech transmitted, as is always the case in the upper side band in the case of single modulation; *cf.* fig. 2. An inverted channel is one in which the highest speech frequencies correspond to the lowest audio frequencies. The fact that in single modulation the upper side band $p+q$ of a modulated carrier wave p is erect, and the lower side band $p-q$ inverted is directly deduced from the fact that in the former case q occurs with the positive sign and in the latter case with the negative sign. In the case of multiple modulation, however, it is possible that $p < q$. Then the lower side band (formed by the difference frequencies $|p-q|$) has the frequency $q-p$, so that it is erect. This is the case in our first group in fig. 4.

[6]) The discrepancy between the initial letters of this Comittee and the abbrevitation used is due to the fact that the abbrevation C.C.I.T. was already being used for the Comité Consultatif International Télégraphique.

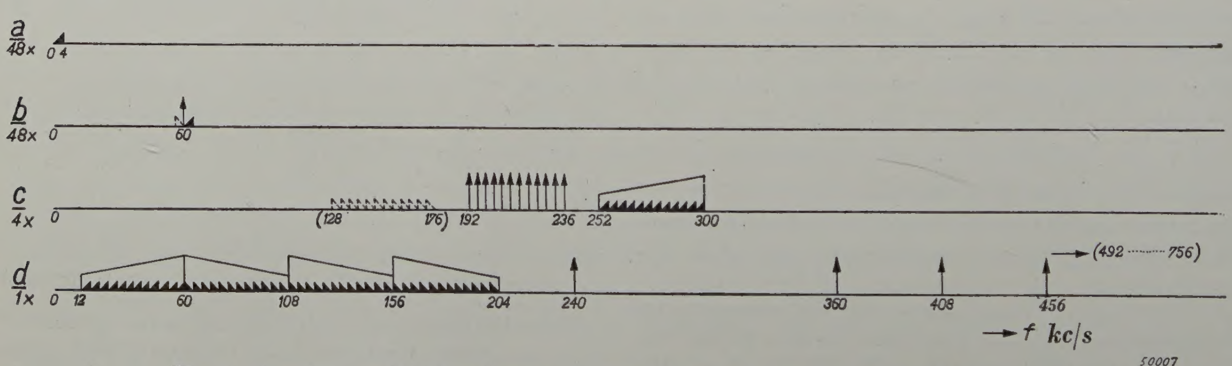

Fig. 5. Complete modulation diagram of the 48-channel system. (a) Audio-frequency channel. (b) Terminal modulation and basic channel. (c) Channel modulation and basic group. (d) Group modulation and 48 channel super-group.

The choice of lower or upper side bands.

Upon the introduction of carrier telephony in Holland in 1938 the 8-56 kc/s band was chosen for the 12-channel system. At first, following British practice, the lower side bands of the carriers 12, 16....56 kc/s were transmitted. In the final development, however, the British Post Office adopted the American practice of using the upper side-bands of the same virtual carriers and a proposal has been made to the C.C.I.F. that this method should be standardized.

Although the channels were otherwise completely in accordance with international requirements, the situation that had arisen would inevitably have led to future difficulties in the engineering of international circuits. Consequently, as developments in cable manufacture gave the prospect of being able to use several groups of 12 channels there was every reason, when renewal of the system became necessary, not only to increase the number of channels but also to give consideration to the recommendations of the C.C.I.F.

At the last meeting of the "Commission de Rapporteurs" of the C.C.I.F. prior to the outbreak of the war (London, December 1938) a resolution was passed to standardize the allocation of the frequency bands in 12-channel systems. For 12 channels in the 12-60 kc/s range the upper side band was chosen. Without discussing systems of 24, 36 or 48 channels it was further recommended that the upper side band be taken for the 312-552 kc/s super-group and again the lower side band for 564-804, 812-1052 and 1060-1300 kc/s. This (at first sight) rather unsystematic choice arose from the solution which the British Post Office had chosen for the transmission of a large number of channels over a co-axial cable. This solution was based on the method of modulation introduced in America, [7]) where in the first stage 12 channels are combined to form a group of 60-108 kc/s and in the second stage five groups are combined into a super-group of 312-552 kc/s, the super-groups then being given their final position in a third stage of modulation.

Though the resolutions of the London meeting had not yet been translated into a general recommendation of the C.C.I.F., [8]) it was deemed advisable to adapt further development in the Netherlands to the conclusions arrived at in London.

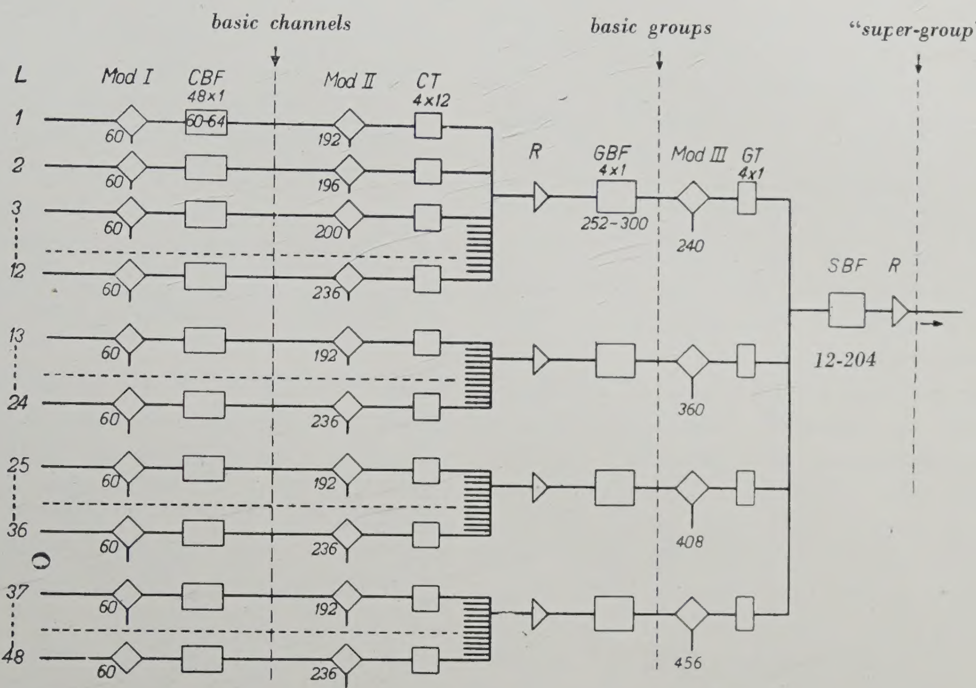

Fig. 6. Block diagram of the modulation system of the 48-channel system. The 48 audiofrequency channels enter at *L. Mod. I.* is the terminal modulator (60 kc/s carrier supplied); *CBF* the channel band filter; *Mod. II.* the channel modulator (channels of 193, 196 .... 236 kc/s); *CT* channel transducer circuit; *R* repeaters; *GBF* group band filter; *Mod. III.* group modulator (group carriers of 240, 360, 408 and 456 kc/s); *GT* group transducer circuit; *SBF* super-group band filter. The filters *GT* are added because the outputs of the four modulators *Mod. III.* cannot be connected directly in parallel without interaction.

This accounts for the choice, illogical as it may appear, of the upper and lower side bands for the four groups of the 48-channel system.

Choice of number of stages of modulation

Continuing the explanation of the choice of the method of modulation for the 48-channel system, we will confine ourselves first to the case where only one system of 12 channels is required.

[7]) C. W. Green, and E. I. Green, A carrier telephone system for toll cables, Bell System Technical Journal **17**, 80-105, 1938. F. J. D. Taylor, Carrier System No. 7, Post Office Electr. Eng. J. **34**, 101-108 and 151-158 1941/42.

[8]) Meanwhile this has been done at the 14th plenary session of the C.C.I.F. at Montreux, in October 1946.

The most obvious method of placing the 12 channels in the standardized frequency band of 12-60 kc/s is to modulate the 12 audio-frequency channels directly with 12 carriers of 12, 16 . . . 56 kc/s, suppressing the lower side band and other undesired modulation products [9]) by means of 12 band-pass filters with pass-bands of 12-16, 16-20 . . . . 56-60 kc/s (single modulation [10]).

Such a system of single modulation has two drawbacks, already noticeable with only 12 channels and even more so as the number increases. In the first place a like number of dissimilar band filters have to be made, and so many different elements in the construction of a system is in itself an objection on the grounds of economy. Furthermore, the higher the frequency the more difficult it is to build a band-pass filter with a certain transmission band, in this case of 4 kc/s. One of the reasons for this is that the coils used in a filter involve losses, and these losses cause, *inter alia*, accentuated attenuation at the edges of the transmission band. This can, it is true, be compensated to a certain extent by equalisers, but it leads to undesired complication and to additional attenuation. The differences in filter performance also have the unpleasant result that the channels of the system do not all have exactly the same loss-frequency curve, even after equalisation. Another difficulty in the design of band filters for high frequencies arises from the inevitable small deviations from the nominal values of inductance and capacity and from the variations of these quantities with temperature. These variable factors lead to a certain relative deviation from the required frequency limits of the filter. The absolute deviation, which is always of importance in carrier telephony, varies directly with the frequency.

These and similar considerations have led to the adoption of multiple modulation for systems with a large number of channels. As a matter of fact various methods of multiple-channel modulation are applied also to systems having not more than 12 channels. To give an idea how far the above-mentioned disadvantages of single modulation are thereby avoided, we shall take as an example the 12-channel system as it was introduced in Holland in 1935 *(fig. 7)*.

As in the 48-channel system described above, each channel was first modulated with a terminal carrier of 60 kc/s to form a basic channel of 60-64 kc/s. The lower side-band (with other undesired modulation products) was suppressed by a

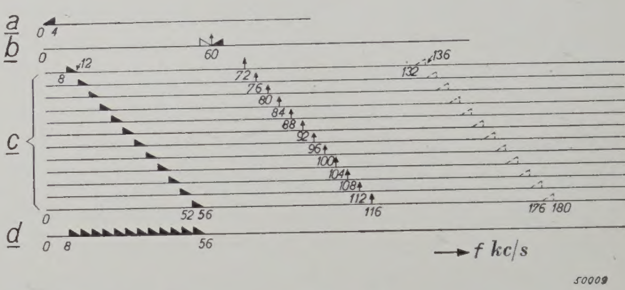

Fig. 7. Modulation diagram of the 12-channel system introduced in the Netherlands in 1935. Double modulation with a basic channel at 60-64 kc/s and final allocation of the channels in the 8-56 kc/s frequency band.

channel band filter. In the second stage of modulation the channels were inverted and brought into their desired places in the final frequency band 8-56 kc/s [11]) by means of 12 channel carriers of 72, 76 . . . 116 kc/s. As may be seen from fig. 7, in the channel modulation all undesired side bands are in the region 32-180 kc/s, well beyond the range of the final frequency band. In principle, therefore, there is no need of a separate filter in each channel after channel-modulation to suppress the unwanted side bands, and this can almost be accomplished by a group filter common to all 12 channels, and having a pass-band of 8-56 kc/s. A very simple filter consisting of a single tuned circuit in each channel is sufficient to suppress any residual minor modulation products within the pass-band of the group filter. (This tuned circuit will be referred to as a "transducer", to distinguish it from a filter and to emphasize that one of its functions is to couple the channel modulators (and demodulators to the busbars without excessive interaction). The group filter is also of simple design owing to the relatively wide band-pass and because there is no functional requirement which necessitates sharp cut-offs.

Compared with the system first described in which single modulation is applied to 12 channels, the objections previously mentioned are partly

[9]) See, for example, F. A. de Groot and P. J. de Haan, Modulators for carrier telephony, Philips Technical Review 7, 83-91, 1942.

[10]) In principle the 17-channel system described in this journal was a development of this idea, but at the request of the Australian P.T.T., who were going to adopt this system, two channels were added to the original 12 on the lower side of the frequency band and three on the upper side, making a 17-channel system in the 4-72 kc/s band. See, *inter alia*, Philips Technical Review 6, 325, 1941 7, 104, 1942; 8 137 and 168, 1946.

[11]) When it was found possible and desirable to use still more channels the Netherlands 12-channel system was extended with eight more channels between 68 and 100 kc/s.

avoided; the 12 channel filters are all identical and the same frequency characteristics are obtained on all channels. The number of carriers, however, is not reduced, and the "universal" channel band filter is slightly more difficult to design than the filter for the top channel of the single modulation system.

Similar considerations hold for systems with more than 12 channels, except that the advantages of multiple modulation are then more pronounced. The channels are assembled in groups of twelve and further processes of modulation are used to form a super-group from a number of groups or (as in the co-axial system) to combine a number of super-groups each of five groups to form a hyper-group. The formation of the basic group of 12 channels in our 48-channel system is exactly analogous to the assembly of the final group in the 12-channel system described, except that the former lies in the 252-300 kc/s-band. Owing to the high frequency of the basic channel (60-64 kc/s) the upper side bands after channel modulation are well separated from the carrier leaks and the lower side bands, so that the unwanted products can, therefore, easily be suppressed in a common group filter. In transposing the four basic groups to form the 48 channel super-group another common filter is needed, the super-group filter. But this, too, is very simple because here again the undesired side bands are well outside the required frequency range (see fig. 4). The number of carriers required is now only 17 for 48 channels and the frequency band of the universal channel filter lies much lower than those of the filters that would be needed with single modulation (up to 200 kc/s).

The result of the comparison between single and multiple modulation may be summarized as follows. The addition of one or more modulating stages, with the larger number of modulators involved, is undoubtedly a complication, but this is more than outweighed by the considerable reduction in the number of different band-pass filters and also, where there is a multiple of 12 channels, in the number of different carriers needed. An important consequence is that with the method of modulation described here, both for 12 and 48 channels, the channel band filter is identical for all channels and in the latter case operates at a low frequency compared with the frequency of the top channel. The advantage of such a universal channel filter from the constructional point of view may be judged from the fact that in a carrier telephone system these filters occupy about 40% of the volume and represent a corresponding percentage of the cost of the whole apparatus. Moreover, a very attractive and logical equipment layout is obtained, as may be seen from the fact that the apparatus consists of units absolutely identical for all channels. We shall refer to the equipment layout again in another article.

Choice of terminal carrier frequency

If it be conceded that the basic channel is a correct engineering solution, there remains the choice of the terminal modulation frequency. We shall consider here briefly the various possible solutions, starting with the simplest case, a 12-channel system with double modulation.

One finds that the choice of the terminal carrier frequency is dependent on the band-width occupied by the group, and to a smaller extent on the frequency allocation of the basic group. For a 12-channel group a band-width of 48 kc/s is necessary and three cases arise according to whether the terminal carrier frequency and the selected side band fall in the following frequency ranges:

(a) In the frequency band to be transmitted (12-60 kc)

(b) Below the frequency band to be transmitted (<12 kc)

(c) Above the frequency band to be transmitted (>60 kc)

Dealing with these cases in the above order we choose, for example, a terminal carrier of say 24 kc/s, so that the basic channel occupies the band 24-28 kc/s. Then if we require an inverted basic group of 12-60 kc/s the frequencies of the channel carriers must be 40, 44 . . . . 84 kc/s. The unwanted upper side bands thus lie between 64 and 112 kc/s, which is just outside the frequency band of the desired group. As in the case of the 48-channel system already described, in which the basic channel occupies the band 60-64 kc/s, we have the advantage that the twelve unwanted side bands can be suppressed with a single group filter. There are, however, objections to this method. Although in theory the modulators might be built with such a high degree of symmetry that neither the input signal nor the channel carrier appears in the output[12]), in practice they do so to a slight extent owing to small unavoidable unbalances. Some of the channel carrier leaks will always fall within the basic group in case (a) and, in addition, if the basic group happens to have a frequency allocation which includes

[12]) See, for example, the article quoted in footnote 9).

the basic channel, cross-talk trouble will be experienced. Thus, in the example considered, each of the channels contributes to the energy in the 24-28 kc/s band, with the result that the channel allocated to this band suffers from troublesome cross-talk from all other channels. This disturbed (fourth) channel would, therefore, have to be left out of the group of twelve, and that would leave an odd number in the system. Irrespective of the location of the basic group, some channel carrier leaks (in the example, those at 40, 44 .... 60 kc/s) lead to operating difficulties in the seventh to twelfth channels, if the method of carrier signalling is applied for long-distance dialling, and are liable to cause possible overload of repeaters and intermodulation cross-talk [13]). Consequently we cannot contemplate the possibility of a basic channel within the basic group; also individual channel filters would be necessary to suppress carrier leaks in case (a), irrespective of where the basic group is located.

We shall now consider the choice of a low-frequency basic channel (case b). A 12-channel system with this method of modulation was, in fact, developed in Germany [14]), with an 8

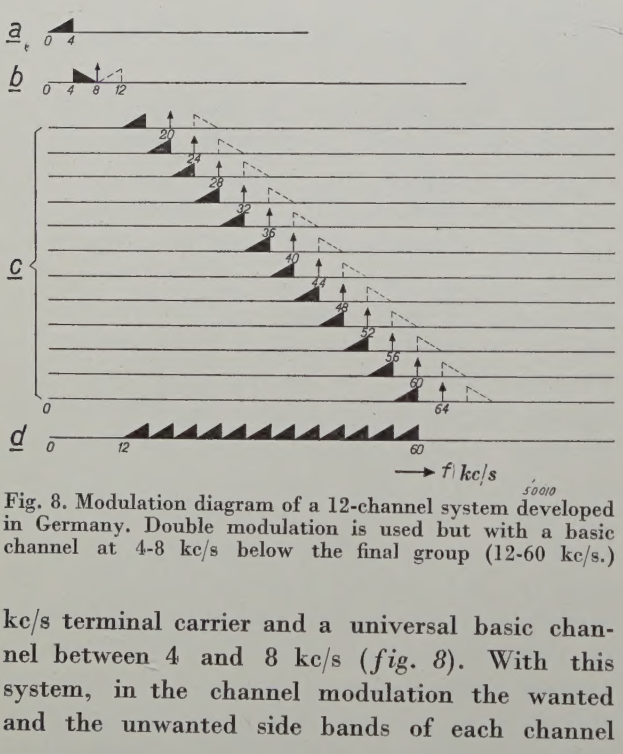

Fig. 8. Modulation diagram of a 12-channel system developed in Germany. Double modulation is used but with a basic channel at 4-8 kc/s below the final group (12-60 kc/s.)

kc/s terminal carrier and a universal basic channel between 4 and 8 kc/s (*fig. 8*). With this system, in the channel modulation the wanted and the unwanted side bands of each channel are separated by an interval of only 8 kc/s. Consequently most of the unwanted side bands, as well as some other modulation products not indicated in fig. 8, lie within the frequency band of the group, so that a common group filter does not suffice and another channel filter is needed.

This is a great drawback compared with the case of a basic channel located at a high frequency. On the other hand, however, a terminal carrier frequency of type (b) has the advantage that the universal channel filter is much easier to make. This is one of the reasons for the original adoption of multiple modulation.

In case (c) the wanted side bands forming the basic group are not only separated from the unwanted side bands but also from the channel leaks. 60 kc/s was chosen for the 48-channel system. It allows for the possible use of a 12-60 kc/s basic group, not containing the basic channel, in special cases, where only a double modulation system is required, without modification of standardized apparatus. The fact, however, that it is easier to make a band filter for case (b) than for case (c) with the same tolerances, is only an incidental argument against the latter, since the difficulty lies in imperfections of the component parts used. As technical development advances these imperfections will be reduced and become of minor importance compared with arguments of a fundamental nature.

The fact that filtering after channel-modulation is much simpler in case (c) is to be regarded as a fundamental advantage of this method.

It was this consideration that led to method (c) being chosen for the first carrier system in the Netherlands.

Meanwhile developments of recent years have already proved this argument to be corrrect. For the construction of the new carrier telephony system we were able to use "Ferroxcube", with which it has been possible to make coils of greatly improved properties, so that there are now no longer any insurmountable difficulties in the manufacture of a band filter for 60 kc/s. This material, indeed, more than fulfils present requirements by a margin adequate to deal also with any future demands which can be foreseen at present.

Channel filter design

The losses in coils are usually expressed by the quality factor $Q = \omega L/R$, where L is the self-inductance, R the series resistance of the coil and ω the angular frequency. Over a relatively wide frequency range Q is practically constant. If,

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[13]) See F. A. de Groot, Signalling in Carrier Telephony, Philips Technical Review 8, 168-176, June 1946.

[14]) D. Thierbach and A. Schmid, Ein Zwölf-Kanal-Träger-frequenzsystem für unbelastete Kabelleitungen, E.T.Z. **60**, 761-768, 1939.
H. Düll, Das Deutsche Zwölfband-Träge frequenzsystem, Europ. Fernsprechdienst, **51**, 43-49. 1939.

however, one considers the effects of dissipation in the frequency characteristic of a series of filters with a pass-band of constant width, as a function of mid-band frequency, then it is not the quality Q that is decisive but rather the ratio $\varrho = R/L = \omega/Q$. With a given coil quality the attenuation distortion in the pass-band increases with the mid-band frequency and other similar difficulties are experienced.

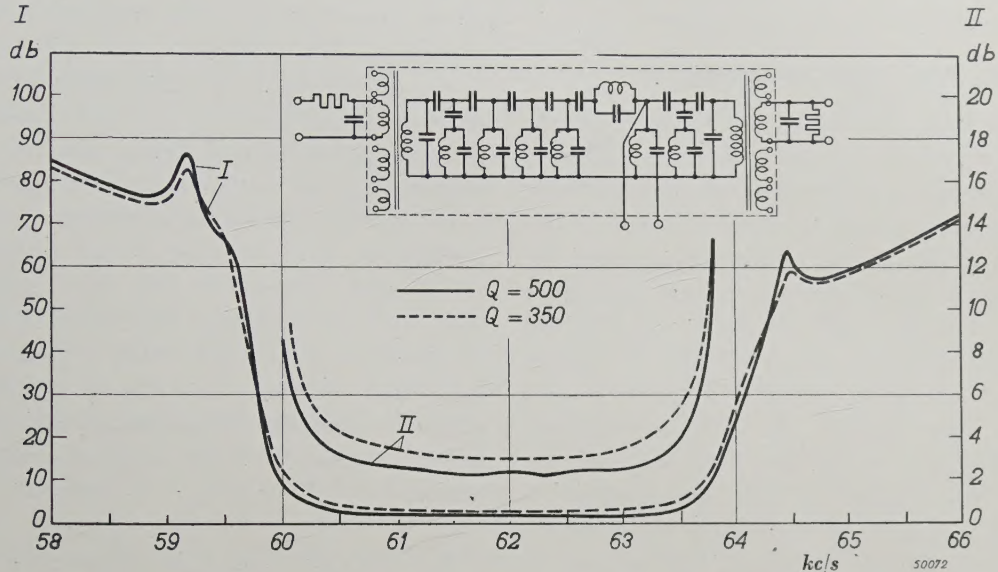

Fig. 9. Attenuation-frequency curve of the channel filter (*CBF* in fig. 6.) of the 48-channel system using coils having a "Ferroxcube" core and $Q = 500$ (fully drawn curve). The dotted curve represents the corresponding attenuation-frequency characteristic obtained when $Q = 350$. For a proper comparison of the attenuation distortion parts of both curves within the pass-band are drawn to a larger scale (see the scale on the right-hand ordinate). The diagram of the filter is shown in the inset; the terminals in the middle of the filter serve for tapping off the carrier signalling when required.

Calculations of the distortion showed that it is desirable to keep ϱ below 750 Ω/H, which means that a coil with $Q = 67$ is required for 8 kc/s and one with $Q = 500$ for 60 kc/s. By way of comparison it may be mentioned that in the 17-channel system previously described in this journal (see note [10])) coils were used which had a Q value of about 220, whilst elsewhere dust cores have been used with which a Q of 300-350 has been attained.

It is well to bear in mind that as ϱ is reduced, and thus the quality Q is improved, the attenuation distortion is not reduced indefinitely. Even with ideal coils and condensers there is always appreciable distortion due to the fact that a band filter can never be exactly terminated with its image impedances. According to the termination conditions, the image impedance at the edges of the pass band tends to zero or to infinity [15]). When a filter is terminated with a constant resistance, as is actually the case in practice, then at the frequencies on the edge of the transmission band reflection losses occur which result in distortion. This, therefore, is the minimum distortion that would be obtained in the case of coils and condensers with infinite Q. As ϱ is reduced so the improvement obtained also diminishes. When ϱ drops from 1500 to 750 the distortion is appreciably reduced, and upon a further drop to 500 or 400 there is still a noticeable improvement, but below that any further improvement has little effect. A simple calculation shows that with a core of given shape and material the Q of a coil is proportional to the linear dimensions; in principle, therefore, any desired Q could be obtained even with an inferior magnetic material if the coils can be made large — which is inadmissible from the constructional point of view. By using "Ferroxcube" as the core material for a coil of 210 cm^3. volume, a size which up till that time would have been considered satisfactory, it was found possible to obtain a Q exceeding the design requirement by a factor of 1.7. This surplus was therefore utilised to reduce the volume of the coil by a factor of $1.7^3 = 5$, so that finally a coil was produced with a P of 750-630 ($Q = 500$-600, for a filter

[15]) See, for example, Balth. van der Pol and Th. J. Weyers, Electrical Filters, II, Philips Technical Review 1, 270-276, 1936, especially p. 274. By using so-called m-sections the frequency range in which the filter impedance is practically constant can, it is true, be widened, but even then the impedance runs ultimately to zero or infinity at the edges of the pass band.

at 60 kc/s) and a volume of 44 cm³. We hope to revert in a later article to the far-reaching consequences this has in the construction of the system. *Fig. 9* shows the attenuation-frequency characteristic of the channel filter built with these coils as compared with the more rounded characteristic obtained at these frequencies with a Q of 350.

"Ferroxcube" also meets the requirements in respect of the temperature coefficient and stability and thus provides a very important component for the construction of the new system.

Design of the three stages of modulation

Reviewing the method of modulation in the 48-channel system in its entirety, we see that it may be regarded as a logical development of that employed in the original 12-channel system introduced in the Netherlands. In the latter system the basic channel of 60-64 kc/s was located just above and therefore outside the final group, which in this case was also the basic group. In the 48-channel system the basic group of 252-300 kc/s is located just above and outside the final super-group, which in this case is also the basic super-group.

Whereas the object of this arrangement is qualitively the same as in the case of the 12-channel system previously discussed, the analogy is quantitively slightly different because one of the group carriers must be lower than the basic group in order to obtain the C.C.I.F. arrangement. When this is taken into account it is found that the basic group must be located above 220 kc/s in order that the lowest group carrier may be just outside the super-group; this, however, is only a small increase above 208 kc/s, which would be necessary to prevent cross-talk due to group modulator unbalances. Owing to the addition of the third stage of modulation the choice of the terminal carrier frequency could now be reconsidered, because unbalance of the terminal modulator can no longer cause cross-talk in the final super-group; but, as already explained, the choice of a frequency of 60 kc/s can be justified on other grounds. Moreover 60 kc/s was already recognised by the C.C.I.F. as a pilot frequency and must, therefore, be generated in any case. Another consideration had some influence in the final choice of the basic group. The group carriers chosen are multiples of 24 kc/s, which is of importance in the design of the carrier supply apparatus. Using a basic group of 252-300 kc/s, group carriers of 240, 360, 408 and 456 kc/s are required in order to provide the channel frequency allocation recommended by the C.C.I.F. If the basic group were located 24 kc/s lower this would be very near the minimum of 220 kc/s mentioned above and would make the filter design problems more difficult.

Demodulation

The process of demodulation [16]) is analogous to that of modulation and also consists of three stages. The super-group is conducted to four group demodulators each supplied with a group carrier of 240, 360, 408 and 456 kc/s respectively. From each of these modulators a basic group of 252-300 kc/s is obtained, which is passed through an individual group filter to attenuate adjacent groups and remove the unwanted side band. Each group is then applied to 12 channel demodulators, each of which is fed with one of the 12 channel carriers of 192, 196 . . . 236 kc/s, so that each demodulator delivers a basic channel in the 60-64 kc/s band. This is selected by the individual channel band filters. Finally, in the 60 kc/s terminal demodulator the 60-64 kc/s band is reduced to the original audio-frequency band.

In conclusion it is to be noted that the system of modulation described here can be freely extended to a system with several super-groups, as is desired for the transmission of several hundred channels *via* a coaxial circuit. In that case a series of five basic groups is combined into a basic super-group, which is transposed to the final hyper-group by a fourth stage of super-group modulation. By selecting for the basic super-group frequencies higher than the band to be transmitted, the advantage of easy suppression of the undesired modulation products is retained in the super-group modulation, whilst retaining also the essential advantage of the system, that all channels are dealt with as uniformly as possible.

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[16]) The process called demodulation is absolutely identical with modulation. One is, it is true, usually inclined to believe that in modulation a frequency spectrum is transposed from low to high frequencies, whilst in demodulation the reverse takes place; or one may well assume that in modulation the carrier wave has a higher frequency than that of the band to be modulated and that the reverse is the case in demodulation. With multiple modulation, however, neither of these two features need be present, as may be seen most clearly in the case of the 240 kc/s group carrier in the method of modulation described here. One may, nevertheless, speak of demodulation, as simply implying that the reception end is meant.

AN IMPROVED METHOD FOR THE AIR-COOLING OF TRANSMITTING VALVES

H. de BREY and H. RINIA.

621.396.694.032.42

A method is indicated which makes it possible in principle to use air for cooling all transmitting valves which are at present cooled with water. The recognised principle is that for effective cooling it is necessary to have a large number of short air passages connected in parallel, and this has led to a system in which the air admitted is divided into a number of air currents each of which serves a definite zone (of short length) of the cooling fins. Once the dimensions of the cooling fins have been chosen, then with a given maximum anode temperature and a given ratio of the ventilator power to the power to be dissipated, the maximum specific anode loading is determined (*i.e.* the dissipation per square cm anode surface). Valves now in use already work with a specific anode load of more than 60 W/cm^2. In principle unlimited total powers can be dissipated. Nevertheless, the cooler may be so small that even for high powers the anode capacity and the weight are considerably less than in other air-cooling systems.

This article describes an air distributor, for distributing the air among the cooling zones, and a particularly favourable and simple construction of the cooling fins.

In a transmitting valve heat is liberated at the anode upon the conversion of D.C. energy into high-frequency A.C. energy. A smaller amount of heat is developed in the filament and the grids. As the power for which the valves were constructed increased, this lost energy also increased. Thus more and more attention has had to be paid to the question of how best to get rid of this heat. An important step in the case of powers above a certain limit was the abandonment of the construction in which a glass envelope entirely surrounds the electrode system and the adoption of a system with an external anode which forms a large part of the valve wall and is cooled with water. Until now this has been the usual construction for transmitting valves with a total dissipation greater than 4 to 10 kW.

There are, however, objections to this water cooling. The anode which is to be cooled is usually at a high potential, for instance 20 kV; the cooling water, on the other hand, comes from the mains at earth potential. An insulating connection is therefore necessary to carry the water to the anode. Along this cooling-water line a voltage gradient of not more than 1 kV/m is permissible, so that the line in question must be quite long. Furthermore, in transmitting installations the cooling-water available is often not of sufficient purity.

A cooling method with air instead of water has long been sought. Before the external anode with water-cooling became customary glass transmitting valves were sometimes air-cooled with a fan. Much more effective is the cooler already described in this periodical for the transmitting valve PA 12/15 [1][2]), which was originally designed for water-cooling. The cooler in question consists of a cylinder of copper or aluminium into which the cylindrical anode is soldered. The cylinder is provided with a number of fins about as long as the anode itself. A fan blows air from the bottom to the top through the slits between the cooling fins. In this way a quantity of heat corresponding to about 10 kW loss in the transmitting valve can be dissipated.

When investigating whether this air-cooling system can also be realized for larger powers, various objections are encountered. These are connected with the fact that at higher powers the anode must be longer, so that with the cooling system described the air passage also becomes longer. During its passage through the slits the air rises in temperature; it therefore cools the fins at the end less than at the beginning, so that in the axial direction there is an appreciable temperature gradient in the anode. This is unfavourable, since it is a question of the maximum temperature occurring in the anode. A second disadvantage of the long air passage is that the slits must be made fairly wide, since otherwise the resistance to the air flow would become large and the fan would have to produce a fairly high pressure. It is necessary to make a compromise here because a widening of the slits, with a given circumference of the anode,

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1) M. van de Beek, Air-cooled Transmitting Valves, Philips Techn. Rev. 4, 121-127, 1939.

2) In the type numbers of the Philips transmitting valves the number in front of the oblique stroke indicates the maximum anode D.C. voltage in kV, that following the stroke the delivered H.F. power (in round numbers) in kW (in the case of small valves in W), in class C adjustment.

is obtained at the expense either of the thickness or or of the number of fins. The former is unfavourable for the heat conduction through the fins, the second means a reduction in the cooling surface which must be compensated by making the fins wider in a radial direction — a measure which promotes the occurrence of a considerable temperature drop in that direction. Thus for high powers one always arrives at coolers of disproportionately large size, which are not only heavy but are also unsuitable from an electrical point of view, especially on short waves, since the anode capacity assumes an undesired large value.

The new cooling system

A cooling system which does not possess the disadvantages mentioned and which in contrast to the older methods can also be employed for transmitting valves of very high power has been realized in the construction to be described in the following. The principle of this system was given by the late Dr. P. H. Clay with an entirely different application in view, namely for the heaters of air engines. The principle can, however, be used in many other fields.

Instead of simply passing the current of air along the whole length of the anode fins it is first divided into a number of air currents, each of which cools only a certain zone of the anode. The way in which this distribution of the air is accomplished will be explained in the following section. Because of the short length of these air channels "in parallel", it is now possible, without the necessity of too high a fan pressure, to make the slits narrow and thus increase their number. A sufficiently large cooling surface is then attained with fins which are narrow in a radial direction, and the cooler thus becomes smaller. In this way also adverse temperature differences are avoided, both in the anode, because of the short length of each cooling zone, and in the fins (radial), because they are narrow.

With the new cooling system neither the dimensions of the anode nor the total power to be dissipated are limited; for a long anode one simply needs more cooling zones than for a short one. With a given ratio of the fan power to the power to be dissipated and with the maximum permissible anode temperature, the specific anode loading (*i.e.* the power to be dissipated divided by the anode surface cooled) depends only on the dimensions of the cooling fins.

The new cooling method is distinguished not only by the above-mentioned subdivision of the air current admitted, but also by a much more economical use of the air than was the case with the older cooling methods. In the older methods large quantities of air were often passed through which increased only slightly in temperature. A much smaller amount of air and thus a much smaller fan is sufficient if the air in the cooler is made to assume a temperature of the same order as the anode temperature. In order to attain this, quite different dimensions of fins and slits are necessary than have hitherto been usual. It is here very much a question of the choice of the corrrect dimensions. By choosing the correct proportions we were successful in reducing the air consumption, which in the cooler previously described amounts to about 1.5 m^3 per minute and per kW of power to be dissipated, and in other models as much as 2-3 $m^3/kW \cdot min$, to 0.8-1 $m^3/kW \cdot min$. At the same time the dimensions and the weight of the cooler have been appreciably reduced.

We shall now deal in turn with the form of the fins and the construction of the air distributor in which the air current is distributed among the cooling zones; a new model for the cooling fins; the question of whether the ventilator should have a blowing or a suction action; the shape of the cooler housing; and how the heat accumulated in the transmitting valve can be dissipated in the event of trouble in the mains.

The fins and the air distributor

In principle one may choose between two forms of fins: longitudinal fins (*fig. 1a*) in planes through the axis of the anode, and transverse fins (fig. 1*b*) perpendicular to the axis [3]). *Figs. 2a* and *b* show how in each case air currents can be passed along short lengths of the fins by means of partitions whose planes are perpendicular to those of the fins.

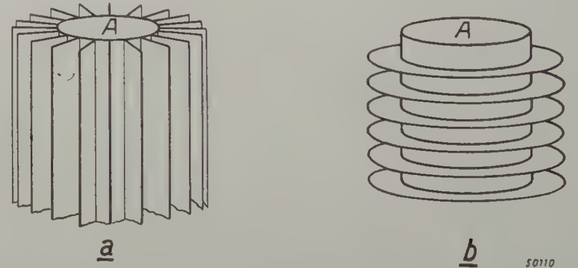


Fig. 1. Anode (*A*) of a transmitting valve, provided with (*a*) longitudinal fins, (*b*) transverse fins. The former are to be preferred.

[3]) We shall not consider here the less practical solutions such as radially directed pins or lengths of wire soldered to the anode surface.

The air currents are obtained from a fan which either blows or sucks the air through the cooler. Let us assume the latter case (we shall shortly see that a blast has certain advantages over suction);

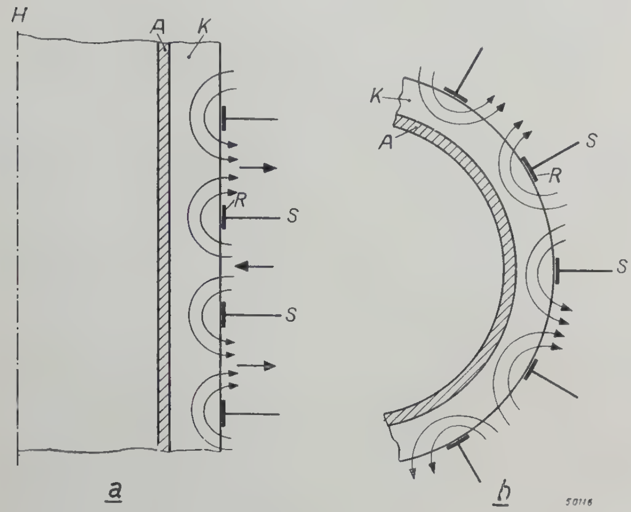


Fig. 2. Partitions divide the cooling fins into zones, each of which is served by a separate current of air; *a*) shows the case of longitudinal fins (cross-section through the axis *H* of the anode), *b*) that of transverse fins (cross-section perpendicular to the axis). *A* is the anode, *K* the cooling fins, *S* the partitions with the rim *R* serving to distribute the air better. Arrows indicate the air current.

it provides a single air current which still has to be divided into the above-mentioned smaller air currents. The way in which the fan can be connected to the air distributor, indicated very roughly in fig. 2, may be seen in *fig. 3* for longitudinal fins, in *fig. 4* for transverse fins.

A clear picture is given by *fig. 5a* of an air distributor for longitudinal fins, which, as will be seen in the following section, possesses some advantages over transverse fins. The anode provided with longitudinal fins is surrounded by piled metal boxes which are alternately open front and back and closed at the sides or closed front and back and open at the sides. As indicated by the arrows, the air is admitted from the left and right and escapes at front and back. The air entering can only escape between the fins to the adjacent higher and lower compartments. In order to obtain a uniform anode temperature "dead angles" between the cooling fins must be avoided, *i.e.* places where the air is not in motion. For that purpose the bottom planes of the compartments are provided with rims (*R* in figs. 2*a*, *b* and figs. 5*a*, *b*, *c* and *d*). The optimum dimensions of this rim and also of the compartments themselves were determined by means of enlarged models where the air was replaced by running water. It was found that the design according to fig. 5*b*, which is the simplest to construct, is adequate, and that the rim need not fit especially tightly around the fins. In agreement with this, in the actual model so much play may be allowed that the transmitting valve can easily be slid into the air-distributor, while the air leak due to this play is insignificant.

Slightly modified models of air distributors will be discussed later.

Form of the fins

This air distributor could be employed with a transmitting valve provided with coarse cooling fins as described in the article referred to in footnote [1]). Thanks to the principle of separate cooling zones this would be a great improvement. An investigation in the Philips Laboratory has shown, however, that much better results can be attained by making the slits much narrower and increasing the number of the fins. The question then arises

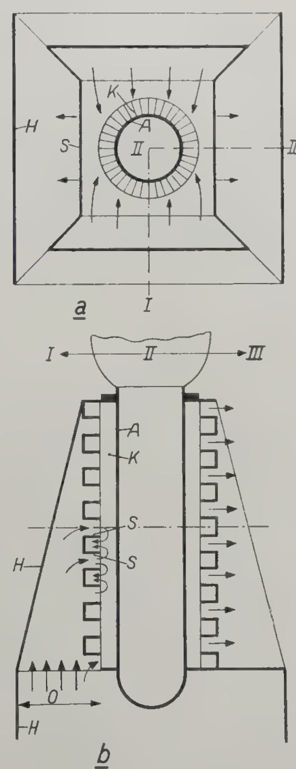


Fig. 3

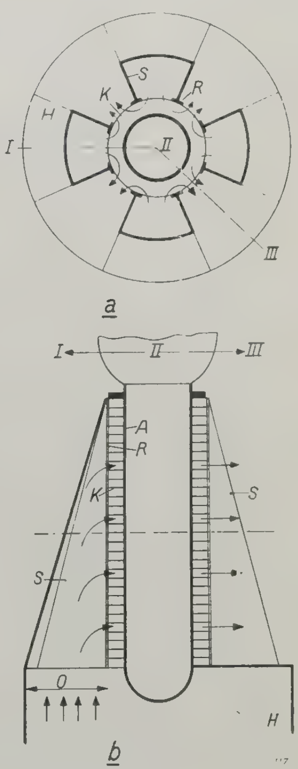


Fig. 4

Fig. 3. Transmitting valve with longitudinal fins and air distributor. *a*) is the view from above on a transverse cross section at a point at half the height of the anode, *b*) in the left-hand half is a cross section through the plane indicated in *a*) by *I-II*, the right hand half is a cross section in the plane *II-III*. *A*, *K* and *S* have the same meanings as in fig. 2. *H* is the cooler housing through which the air is admitted from below *via* the openings *O*.

Fig. 4. Transmitting valve with transverse fins and air distributor. *a*) shows the view from above of a transverse cross section at a point at half the height of the anode, in *b*) the left and right-hand halves are cross sections in the planes indicated in (*a*) by *I-II* and *II-III*. The letters have the same meanings as in fig. 3.

as to how to construct an anode with such fine fins. The problem of heat contact between the anode and the cooling fins then also becomes prominent. In this respect the ideal must be considered to be the construction of anode and fins of copper in one piece, but the casting or fraising of an object with such fine fins is very difficult. The fins must therefore be attached to the anode, and the best way is to solder them on; for good heat conduction a pure metal (for example tin or cadmium) rather than an alloy is used as solder.

As already stated, there is a choice between two forms of fins: longitudinal and transverse. An objection to the latter form is that due to fluctuations of temperature the ring-shaped fins may work loose, which is not the case with longitudinal ribs. A very simple solution has been found for the problem of their construction: strips of copper, first folded as indicated in *fig. 6*, are soldered side by side on the anode until its whole length is covered. For practical reasons a single strip as wide as the length of the anode is not used, but strips only a few cm (normally 4 cm) wide placed side by side. The heat exchange with the air could be further improved by corrugating the fins or making their surface rough. The strip with the dimensions given in fig. 6 can be made in any length desired and may thus serve for anodes of different diameters (the transverse fins of fig. 1*b* on the contrary would have to be made in as many sizes as there are anode diameters). The result may be seen in *fig. 7*. The anode of the transmitting valve TA 12/20 shown here is covered by seven strips. Around the circumference of the anode, whose diameter is 60 mm, there is room for about 210 fins 0.3 mm thick, with slits between 0.6 mm wide at the inside and 0.9 mm at the outside. The breadth of the fins is 10 mm.

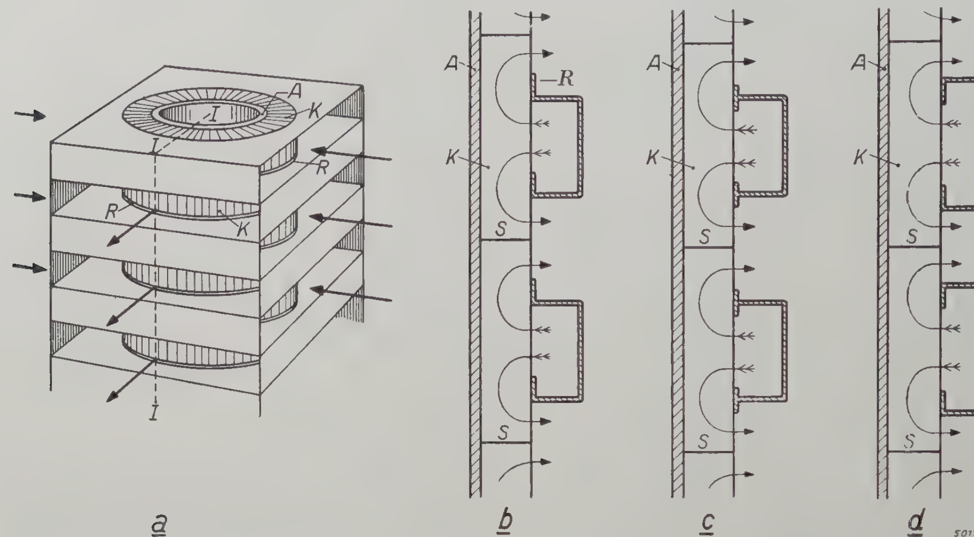


Fig. 5. *a*) Air distributor in which is inserted the anode *A* with longitudinal fins *K*. The air enters from the left and right in the first, third, fifth, etc. compartments, flows between the fins to the intermediate compartments and leaves the latter at the front and back. *R* is the vertical rim for directing the vertical air current between the fins. *b*), *c*), *d*). Cross sections of the air distributor and the anode by the plane *I-I-I* (*cf. a*). Three variants are shown of how the vertical rim *R* may be constructed. The simplest form, (*b*), is found to be satisfactory. The junction *S* where two strips come together lies in the middle of an outlet and therefore does not interfere with the vertical air current.

Where two strips come together, as at *S* in fig. 5*b*, the fins do not in general form prolongations of each other. Such a joint might hinder the vertical

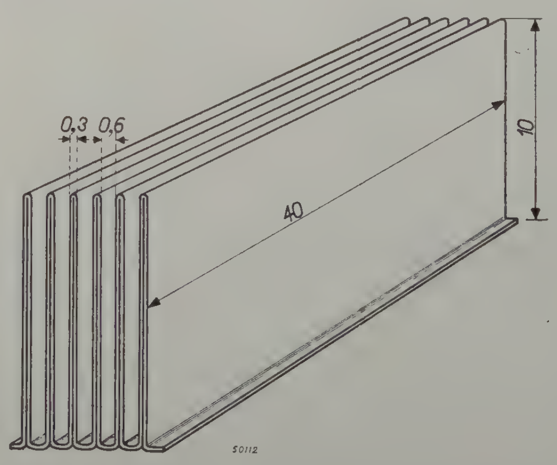


Fig. 6. A copper strip of 0.15 mm thickness is folded in the manner indicated (dimensions in mm) and then soldered to the anode. Such strips can be made in any length desired.

air current. In order to prevent this it is so arranged that the joints fall just in the middle either of an inlet or outlet opening (in fig. 5*b* an outlet). Each strip thus forms a zone which is cooled by a separate air current.

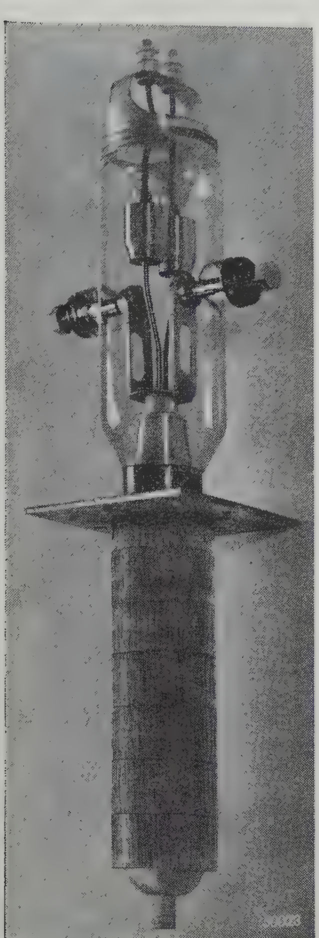


Fig. 7. Seven strips like that shown in fig. 6 are soldered onto the anode of this transmitting valve type TA 12/20.

In order to obtain a temperature distribution over the anode as uniform as possible the air must be made to penetrate deep into the slits everywhere. This is promoted by leaving a small annular opening between adjacent zones, for instance by placing the strips on the anode not side by side in contact but at a slight distance from each other. For cases with a very large dissipation per square cm surface this may be an advantage.

With the construction shown in fig. 7 it is possible to dissipate 20 kW (*i.e.* 4800 cal/sec) at a maximum anode temperature of 150° C and a temperature of the air admitted of 25° C, and with an air consumption of 20 m³/min. This air current requires a difference in pressure at the fan of about 12-15 cm water column and is furnished by a fan whose motor uses about 1 kW (5 % of the power to be dissipated).

Blast or suction?

The question must be considered whether the fan should blow or suck; in other words whether it can best be placed in the inlet or in the outlet connection. The former is preferable on the following grounds.

Whichever of the two solutions is chosen in a given case, a certain volume of cold air must always enter the air distributor per unit of time. In order to maintain this air current the fan must in both cases provide the same difference in pressure. The two solutions differ, however, in the fact that with blowing there is cold air in the fan and with suction warm air. From the point of view of construction the latter is less desirable, so that for that reason alone it is preferable to place the fan at the inlet.

There is, however, still another argument in favour of that arrangement. The effective power P which the fan supplies to the air can be divided into a potential and a kinetic part:

$$P = pV + \tfrac{1}{2} Mv^2, \quad . \quad . \quad . \quad . \quad (1)$$

where p is the difference of pressure caused by the fan, V the volume and M the mass of the air passing per unit of time, and v the velocity of of the air.

If we give the quantities dependent on temperature the indices 0 and 1 respectively, as they relate to cold and warm air, the following is valid for blowing:

$$P_0 = pV_0 + \tfrac{1}{2} Mv_0^2,$$

and for suction:

$$P_1 = pV_1 + \tfrac{1}{2} Mv_1^2.$$

If T_0 is the absolute temperature of the cold air and T_1 that of the warm air, then $V_1 = V_0 T_1/T_0$ (the pressure difference p is small compared with atmospheric pressure) and $v_1 = v_0 T_1/T_0$, so that apparently $P_0 < P_1$. Thus by having a fan with a blowing action a smaller type may be used and the energy consumption will be slightly less than when the fan works by suction.

The cooler housing

The cooler housing serves for the connection of the inlet and outlet lines to the air distributor. When the fan is placed in the air inlet an outlet channel may be entirely omitted if the warm air is allowed to flow freely out of the air distributor. If this should raise the temperature of the space into which this air escapes too much, the warm air must be conducted to the outside. The system can be arranged for this without much difficulty, but it is really only necessary for high powers.

The shape and the choice of material of the cooler housing are determined mainly by the following considerations:

1) the (electric) anode capacity must be kept as small as possible;
2) dielectric losses must be avoided;
3) where the material is in contact with the distributor it must be resistant to temperatures of 150 to 180 °C;
4) the fan must be insulated from the anode.

The points mentioned under (2) and (3) present

objections to making the housing completely of insulating material, which objections can only be overcome by the use of ceramic material. Since, however, ceramic parts of the desired shape and dimensions were not immediately available, we at first tried a metal casing fitted over the air distributor and connected with the fan by an insulating pipe. This casing must be as small as possible in view of the capacity.

If it is a question of two valves in push-pull connection, the capacity between the anodes is kept lowest by arranging the air distributor for unilateral admission of the air, and by causing the air to enter at the sides of the cooler facing away from each other.

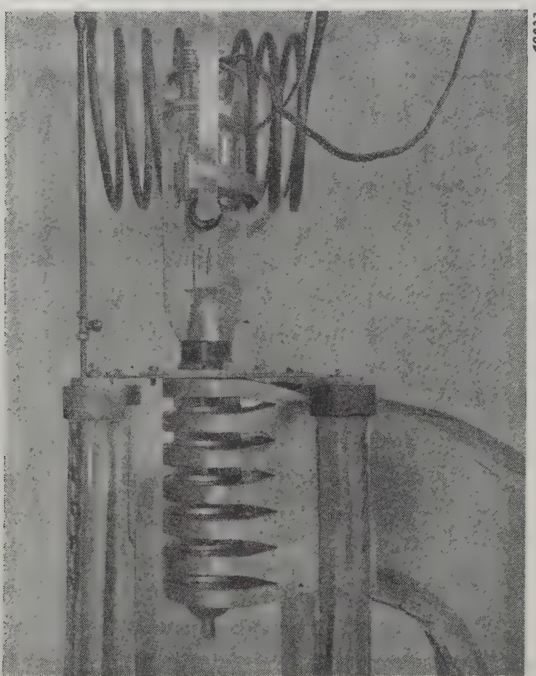


Fig. 8. Transmitting valve TA 12/20 with an air distributor into which the air is led from one side, instead of from two sides as shown in fig. 5*a*. The warm air flows away freely.

Fig. 8 shows how in such an air distributor annular channels lead the air around to the corresponding cooling zones. Between two anodes, each provided with such a cooler and placed with their axes 40 cm apart, the capacity amounts to about 20 pF, which is not objectionable for waves longer than 10 m.

The designer of transmitters may object to this arrangement on the ground that the inlet channels obstruct access to the transmitter valve and other components of the apparatus. From his point of view it would be ideal to lead in the air from below and let it escape above. In the models sketched in figs. 3 and 4 that was the case, but the dimensions of the cooler housing and thus also the anode capacity are fairly large in those cases. This can be met to some extent by proceeding as in *fig. 9*. Here the lower half of the anode

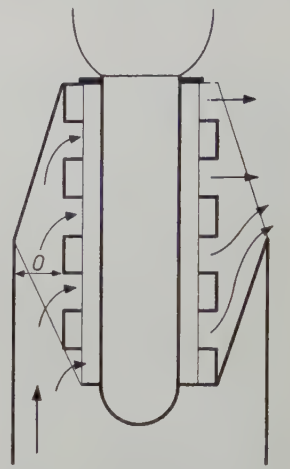


Fig. 9. Here the anode has been allowed to sink halfway into the cooler housing, so that only the air cooling the upper half of the anode flows through the openings *O*. These openings, and thus also the dimensions of the cooler housing, can therefore be made smaller than in the designs according to figs. 3 or 4. This results in a decrease of the anode capacity.

is situated inside the air inlet tube. Through the openings indicated by *O* around the cooling fins only half as much air now flows as in the design according to figs. 3 and 4; as a result in the case of fig. 9 these openings can now be made smaller without involving a higher air resistance, which results in smaller dimensions of the cooler housing and thus a smaller anode capacity.

A further elaborated form of this construction is shown in *fig. 10*, where the cooler housing consists partly of ceramic material. The warm air flows out freely through openings in the cap. The air distributor consists of piled aluminium

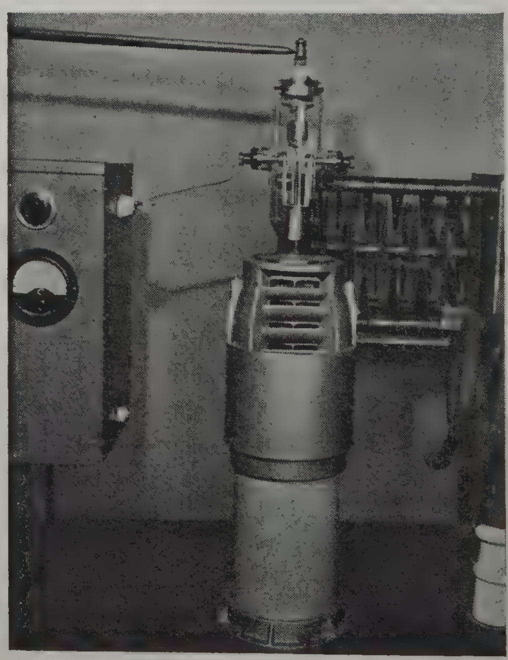


Fig. 10. Photograph of a cooler with air admitted from below. The lower part of the cooler housing consists of ceramic material.

castings which are stream-lined to keep the air resistance as low as possible. In *fig. 11* the form of these castings is shown. A separate outlet channel is also present here.

In conclusion it should be mentioned that it is desirable to allow the air, before it enters the fan, to pass through a filter which retains dust and insects.

Dissipation of heat upon failure of the mains

In the event of a breakdown in the mains supplying the transmitter as well as the motor of the fan, the heating current and the anode current of the transmitting valve are both interrupted. In the filament and the grids, however, a certain amount of heat is still stored up; the heat capacity of the anode and the cooler is so small in the construction described that the anode temperature would rise higher than is permissible if the cooling air also immediately ceased to flow. Owing to the moment of inertia of the fan and the rotor, however, the fan continues to run for some time after the mains voltage has dropped out, in most cases long enough to prevent the overheating in question. If necessary, a fly-wheel may be attached to the motor shaft.

Applications to higher powers

The above examples of the new cooling system all refer to the valve TA 12/20. The anode of this valve is loaded with 45 W/cm², at a dissipation of 20 kW. It is quite possible to go as far as 60 W/cm² with the same fins, with the quite permissible anode temperature of 180 °C and using a fan whose motor consumes no more than for instance 5% of the power to be dissipated. The temperature of 180 °C lies far enough below the melting point of the tin solder used (232 °C). When a solder with a higher melting point is used (for example cadmium, 321 °C) the anode temperature could be raised higher than 180 °C.

For several larger types of transmitting valves — which, like the TA 12/20, have until now been cooled with water — we find the following values of the dissipation and of the specific anode loading:

Transmitter valve types	Dissipation kW	Specific anode loading W/cm²
TA 12/35	22.3	40
TA 18/100	77	45
TA 20/250	145	85

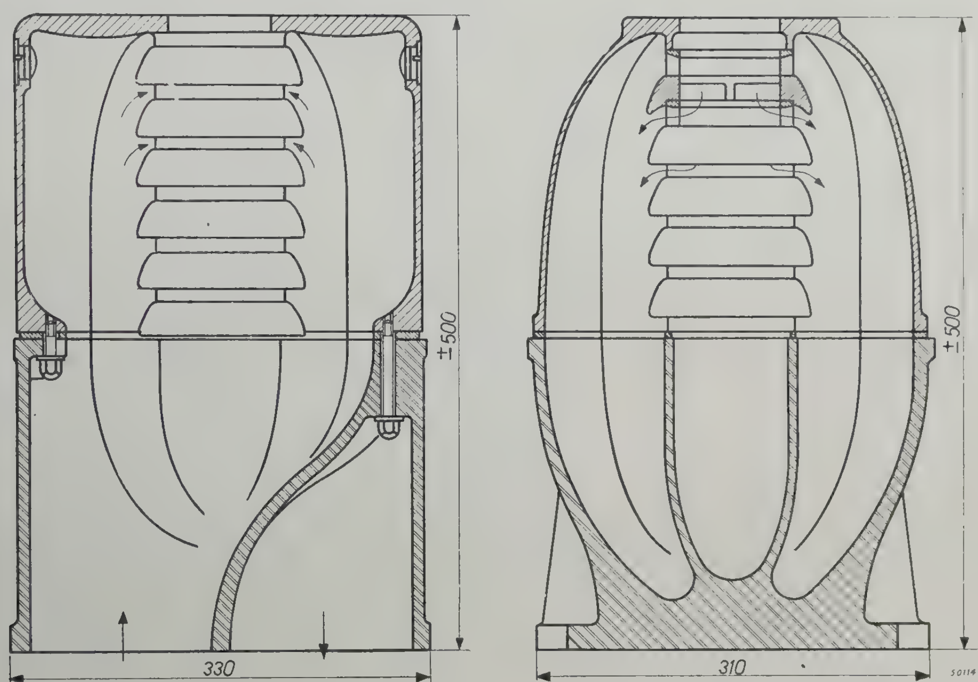


Fig. 11. Cross sections of a cooler with an inlet and outlet channel each describing 1/4 of a winding of a helix. The air distributor consists of stream-lined aluminium castings one on top of the other. The cooler housing is partly of ceramic material. The main dimensions are given in mm.

From the values of the specific loading it is evident that for the first two types in the list the new cooling system can be used unaltered in the form described. This is not, however, the case for TA 20/250, the largest transmitting valve made by Philips. By increasing the area of the cooling fins, making the slits narrower and dividing the anode into a larger number of narrower cooling zones, it is, however, possible also in this case to replace the water-cooling of this valve — which requires 130 litres of water per minute — by air-cooling.

In *fig. 12* several graphs [4]) are given which relate to a certain anode, cooled in the manner indicated by fig. 8, with a maximum temperature of 180 °C. The anode in question is that of the valve TA 12/35; when cooled with water it can dissipate 22 kW; cooled with air by the old system (described in the article referred to in footnote [1])), 10 kW. From fig. 12 it may be read off that the same anode cooled by the new method can be used for a transmitting valve which dissipates 40 kW for example, provided 31.5 m³ of air is supplied per minute. For this an air pressure of 23 cm water column is required. A fan is needed with a motor using about 2.3 kW (6% of the dissipation). With the dissipation of 40 kW mentioned the specific anode loading is about 70 W/cm².

It also follows from fig. 12 that it is no use to attempt, at constant anode temperature, further to increase the specific anode loading by increasing the amount of air V_0 passing through. The pressure difference required is approximately proportional to V_0^2, the fan power to pV_0, thus to V_0^3; the dissipation, however, is proportional to V_0. The "relative fan power" (*i.e.* the fan power divided by the dissipation) is thus proportional to V_0^2; it therefore increases rapidly upon increasing the specific anode loading. The solution

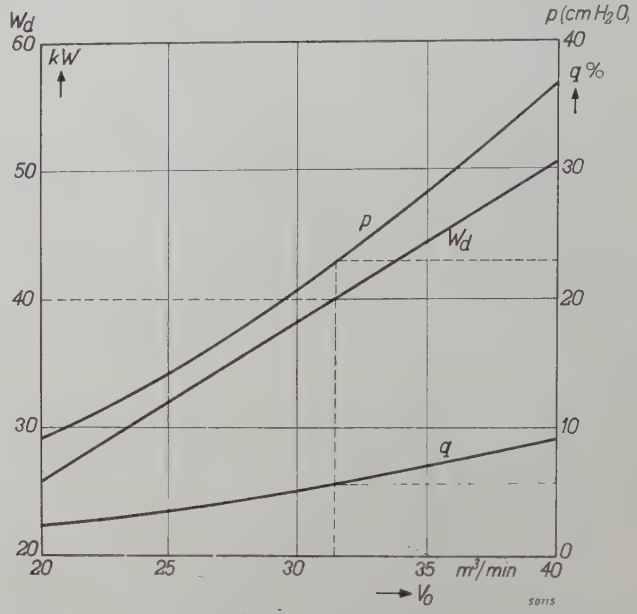


Fig. 12. Graphs relating to an anode like that of the transmitting valve TA 12/35 with a maximun temperature of 180 °C. The following are plotted as functions of the necessary amount of cold air V_0 in m³/min: the total dissipation W_0 in kW, the required pressure difference p in cm water column, and the power taken up by the fan motor in percent (q) of the dissipation.

must then be found, as already stated for the case of TA 20/250, in choosing different dimensions of the fins and slits and length of the zones, and/or permitting a higher anode temperature.

In conclusion it should be noted that the application of the cooling system described need not of course be restricted to transmitting valves, but may prove useful in several other fields.

[4]) These graphs are based upon measurements carried out by J. C. van Warmerdam, who has also made an important contribution towards the practical construction of the coolers described.

A NEW ELECTRON-MICROSCOPE FOR 100 kV

In view of great interest shown in recent years in the electron-microscope for laboratory work, Philips have developed a new instrument as illustrated above. This electron-microscope is based on the pioneer work carried out in the Laboratory for Technical Physics of the Technical High School at Delft; its principles have been recently described in an article in this journal [1]): the magnification is continuously variable from 1000 × to 150 000 ×; focusing is greatly facilitated by a special method; with a few simple turns of the hand one can produce on the screen, instead of the magnified image of the object, an electron diffraction pattern of a part of the specimen previously screened and selected.

In this photograph the microscope tube is seen directed obliquely upwards. It will be noted that it has an exceptionally large viewing screen on which the image appears. Details of the image can be examined under a magnifying lens (turned away to the side in the picture). Micrographs on a 4 × reduced scale can be taken on 35 mm film with the aid of a camera built into the tube. The stabilized high voltage is supplied by a generator, on the left of the photograph, in a special housing connected with the electron-microscope by a flexible cable.

[1]) J. B. Le Poole: A new Electron-Microscope with Continuously Variable Magnifications, Philips Techn. Rev. 9, 33, 1947.

IMPROVEMENTS IN THE CONSTRUCTION OF CATHODE-RAY TUBES

by J. de GIER and A. P. van ROOY.

621.385,832

The use of a flat glass base with chrome iron pins has long been known in the manufacture of radio valves. By applying this construction to cathode-ray tubes more space has become available and it has thus been possible to introduce some improvements of an electron-optical nature without having to make the tube any larger. Furthermore, a new technique has been developed for the mounting of the electrodes which ensures better centering. As a result a sharper light spot is obtained, particularly at the edge of the screen. These improvements have been incorporated in a new oscillograph tube, type DG 7-3, which also has an electric screening that prevents the two pairs of deflecting plates affecting each other electrically at high frequencies.

In the construction of cathode-ray tubes for use in an oscillograph a number of improvements have been worked out in recent years which have led to a much better quality of the image. We will discuss these improvements with reference to a new type of tube (with electrostatic deflection in both directions) in which they have already been incorporated. In the main these are improvements of an electron-optical nature, the principles of which are not new but the application of which would have involved longer tubes if the old method of construction had been maintained.

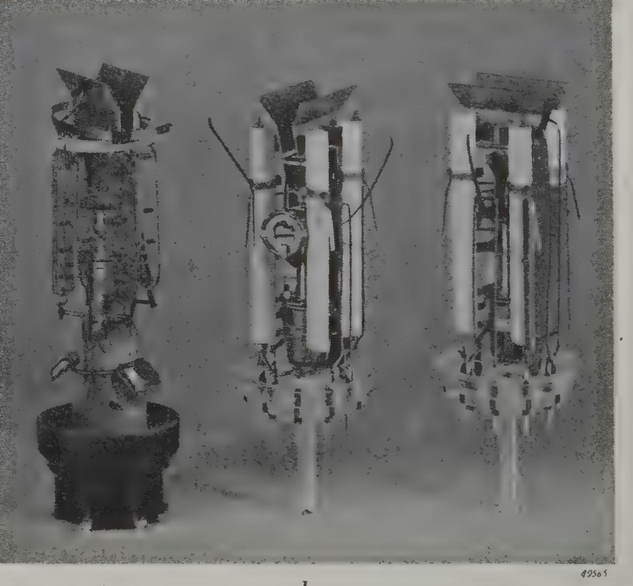
These improvements, which we shall now deal with successively, consist of:

1) changes in the leads and in the shape of the envelope;
2) a new method of mounting;
3) electron-optical improvements resulting from 1) and 2);
4) a screening between the pairs of plates.

Changes in the leads and in the shape of the envelope

Hitherto, in the manufacture of cathode-ray tubes, a so-called "pinch" had been used for carrying the electrical leads through the glass (*fig. 1a*). Owing to the large number of leads required for these tubes (eight or nine) plus, in some cases, a number of supports to which the electrodes are affixed, cross-shaped and ring-shaped pinches have had to be employed, which were not at all satisfactory from the glass-technical point of view. Moreover — also in the simpler forms as illustrated in fig. 1*a* — the distance between the pinch and the point where it is fused in had to be several centimeters in length to prevent the pinch from being heated to too high a temperature in the fusing process; furthermore the nature of this process is such as to cause considerable variations in this length, with the result that specimens of the same type of tube are apt to show differences in length, which of course have to be allowed for in the construction of the apparatus in which the tubes are used.

Difficulties of the same nature had been experienced also with radio valves and there they were overcome by replacing the pinch by the flat base



a b c

Fig. 1. *a*) The electrode system of a cathode-ray tube (DG 7-1) with the old glass construction: leads passed through a "pinch" and the electrodes fixed by means of glass "beads".
b) and *c*). The electrode system of the new cathode-ray tube (DG 7-3) with glass-technical improvements. Leads as in radio valves of the "Key-Valve" type: nine chrome iron pins in a base of moulded glass, the cap being dispensed with. Electrodes fixed in sintered glass contained in ceramic rods.

of pressed glass with a number (*e.g.* nine) of chrome iron pins. [1]) Figs. 1*b* and *c* show how the assembly of the inner parts of a cathode-ray tube can be mounted on such a standardised glass base. The saving in length compared with fig. 1*a* is already noticeable here, but it is still more apparent in the cross-sectional drawings of *figs. 2a* and *b*. This

[1]) Philips Techn. Rev. 4, 170-175, 1939 and 6, 321-328, 1941.

saving in length is due partly to the fact that the outer ends of the lead pins serve at the same time as contact pins. The base cap seen in fig. 1*a* is thus dispensed with entirely, whilst, moreover, there are no longer any variations in length due to the cementing on of the base cap. Furthermore, the

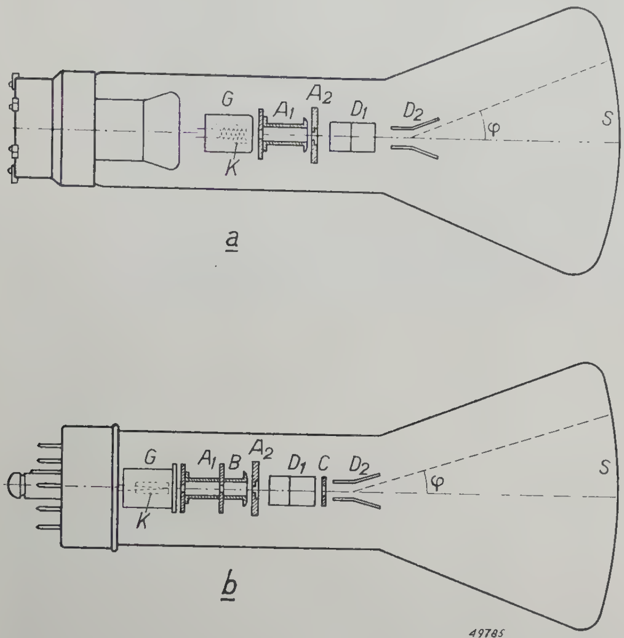


Fig. 2. Diagrammatic cross section of a cathode-ray tube,
a) with pinch (type DG 7-1),
b) with moulded glass base (type DG 7-3).
In both cases the electron gun consists of the indirectly heated cathode *K*, the control grid *G*, the focusing anode A_1 and the final anode A_2. D_1 and D_2 are the pairs of plates for deflecting the electron beam in two directions perpendicular to each other. In *b*) *B* is a diaphragm, *C* a part of the electric screen between the pairs of deflectors. The replacement of the pinch by the flat base gives a gain in space which is utilised for the greater part to lengthen the distance between the deflectors and the screen (*S*). In this way, for a given size of picture, the maximum deflection angle φ of the beam is reduced, which has several advantages.

fusing of the glass base onto the accurately cut envelope can be done with much narrower tolerances than was possible with the old method.

Figs. 1 and 2 both relate to an oscillograph tube with a screen diameter of 7 cm, figs. 1*a* and 2*a* being those of a tube type DG 7-1, while figs. 1*b* and *c* and 2*b* are of a new tube [2]) type DG 7-3, a photograph of which is reproduced in *fig. 3*. The saving in length previously referred to averages about 30 mm on an overall length of approx. 150 mm; how this has been utilised will be shown later on. The variation in length has been reduced from 15 mm to 6 mm, which is all to the good for the construction of the apparatus.

From the electrical point of view the flat glass base has the advantage over the pinch with base cap in that there is a smaller capacitance between two adjacent pins or wires. This we will revert to in the last part of this article.

As to the shape of the envelope of the DG 7-3 tube it is to be noted that the part which is lined with the fluorescent layer is flatter than that in the older types, whilst the curvature of the end where it bends round into the conical face has a smaller radius (compare figs. 2*a* and *b*). As a result the useful screen diameter is relatively large, which is of importance when considered in combination with the improved sharpness of the light spot at the edge of the screen, which will be discussed farther on.

New method of mounting

Before proceeding to discuss the improvements in the assembly of the electrode system we would remind our readers that this system comprises two groups of electrodes. Those of one group form together the "gun" supplying a beam of electrons, which can be deflected in two directions perpendicular to each other by the electrodes of the other group, the deflecting plates .All these electrodes must be accurately fixed in relation to each other, and therefore in the assembling of the various component parts they are "threaded" in their proper sequence on a centering pin with spacers in between, after which the whole of the mount is secured in a gauge. The electrodes are provided with radially directed supports, or poles, which have to be fixed in some way or other to strong insulators.

In the old method of mounting three or four "beads" were used, small glass rods which were heated to the softening point and into which the supporting poles of the electrodes were then pressed in. After the last bead had cooled down the centering pin and spacers were removed, leaving a mount such as is shown in fig. 1*a*. In actual practice, however, it is not easy to get invariably good results with this "bead technique": if the bead is over-heated slightly then the glass begins to flow, whereas if the temperature is not quite high enough the glass does not adhere properly to the metal support pressed into it, with the result that after cooling the support works loose; consequently the mount is then no longer exactly centered and this ultimately has an adverse effect upon the sharpness of the spot of light. The drawback of the flowing of the glass is particularly evident when soft glass is used, whilst unsatisfactory adhesion to the wire occurs particularly with hard glass; a good compromise cannot be found,

[2]) A description of an oscillograph incorporating this tube will appear in this journal shortly.

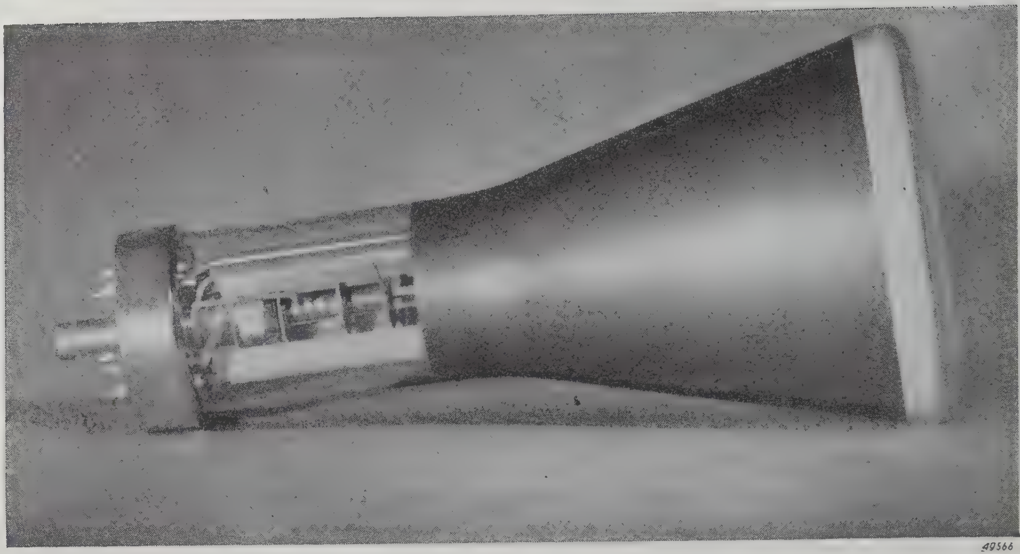


Fig. 3. The new oscillograph tube DG 7-3. Screen diameter 7 cm, overall length approximately 15 cm. The cap on the left protects the pumping stem and has a stud, so that the tube fits into the socket in only one way and the pins are automatically connected in the right way.

also because of the fact that only those kinds of glass can be used which have a coefficient of expansion not differing too much from that of the wire used for the metal supports.

During recent years a new technique has been developed whereby the glass beads have been replaced by ceramic rods (*fig. 4*) having a groove filled with sintered glass [3]). Thanks to the heat resistance of the ceramic material, for the mounting of the electrode system this rod can be heated till the sintered glass is liquefied. The glass is held in the groove by capillary action and readily flows round the electrode poles inserted in it,

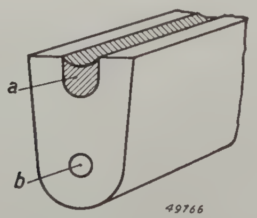


Fig. 4. Section of one of the ceramic rods used in the new mounting technique in the place of the glass beads. *a* is a channel filled with sintered glass. The opening *b* is for a supporting pole, which is afterwards welded to a lead pin.

so that an excellent adhesion is obtained. Figs. 1*b* and *c* show the electrode system of the oscillograph tube DG 7-3 mounted in this way. This method, which thus allows of a more accurate mounting and, moreover, saves time, is already being applied also for other types of tubes.

Electron-optical improvements

As already mentioned, the replacement of the pinch by the flat base meant a saving of about 30 mm in length. If we leave the dimensions of the tube and of the electrode system roughly unchanged, then the distance between the deflecting plates and the screen is increased by that amount. The angle φ (fig. 2) through which the electron beam has to be deflected to describe on the screen an image of a certain maximum size decreases approximately in inverse proportion to that distance. In several respects it is advantageous to have a small angle. In the first place it means greater deflection sensitivity: less tension is required on each pair of plates to give a certain deflection on the screen. The sensitivity of the new tube (DG 7-3) is in fact about 15% greater than that of the older types DG 7-1 and DG 7-2. But a still more important result of the smaller deflection angle is that it greatly reduces the errors of deflection causing defocusing at the edge of the screen.

The manner in which one of these errors of deflection arises is shown in *fig. 5*. The electrostatic "lens", formed by the electric field between the focusing anode A_1 and the end anode A_2, focuses the electron beam in a round spot P on the screen; the tension between the deflecting plates D'-D'' (the other pair of plates is disregarded here) is assumed to be still zero. When applying a positive voltage to D' and a negative voltage (with respect to the final anode) to D'' the electrons in the beam on the side near D' are accelerated whilst those on the side near D'' are retarded. Now, with a given tension between the deflecting plates, the deflection of an electron beam is the smaller according as the velocity of the electrons is higher. Therefore the electrons near D' will undergo a smaller change in direction than those near

[3]) Various other applications of sintered glass are dealt with in an article by E. G. Dorgelo, Philips Techn. Rev. 8, 2-7, 1946.

D''; they strike the screen at P' and P'' respectively. The originally circular spot of light P becomes an oval spot $P'P''$. Calculations show [4]) that the magnitude of this error of deflection is proportional to the second power of the mean deflection angle, so that a relatively small reduction of the latter is sufficient to reduce the error appreciably.

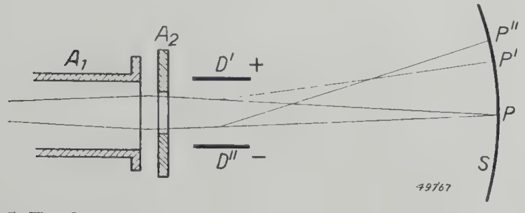


Fig. 5. Explanatory illustration of one of the errors of deflection. The "lens" formed by the electric field between the focusing anode and the anode (A_1 and A_2 respectively) concentrates the electrons of the beam into a round spot P on the screen S, so long as the tension between the deflecting plates D' and D'' is zero. P' and P'' are points where the outermost rays of the beam strike the screen when there is a voltage of the indicated polarity between D' and D''.

Another cause of unsharpness lies in the highly inhomogeneous field at the edges of a deflecting plate causing defocusing when the electron beam passes very closely to the plate. In the tube DG 7-3 the distances between the plates are the same as in the corresponding older types, but thanks to the smaller deflection angle the beam can be kept sufficiently far away from the plates to avoid any trouble on that account.

The greater distance from the lens to the screen — to which the advantages just mentioned are to be ascribed — has, however, also a less favourable effect. The magnification, as given by the ratio of the lens-screen distance to the lens-cathode distance [5]), is thereby increased and results in reduced sharpness of the light spot on the screen. In order to avoid this effect, part of the extra length available has been utilised to increase the lens-cathode distance so as to reduce the magnification and thus give a greater sharpness in the middle of the screen. The gain in sharpness at the edge of the screen due to the reduced errors of deflection is much greater.

This increase in the lens-cathode distance has been obtained by extending the focusing anode (A_1 in fig. 2). At the same time a diaphragm (B, fig. 2*b*) has been introduced, such as is usual in other types of cathode-ray tubes. By limiting the beam diameter a diaphragm contributes towards greater sharpness of the light spot. In principle the diaphragm could be placed anywhere in the beam in front of the deflecting plates, but by placing it in a field-free space — such as in the middle of the tubular focusing anode — it does not need to be so precisely centered and, moreover, it avoids undesired effects caused by secondary electron emission. The secondary electrons released from the diaphragm then all return to the wall of the field-free space without any chance of their being drawn into the beam; such would happen if the diaphragm were placed in the final anode, for owing to their very low velocity the secondary electrons would then all be driven onto the deflecting plates and constitute a troublesome current load. The secondary electrons might also be taken up in the beam if the diaphragm were placed at the outer end of the focusing anode, because after passing the final anode their velocity is lower than that of the electrons coming from the cathode (they have not passed through the cathode-focusing anode voltage difference)and consequently they would be sent off at a greater angle by the deflecting plates and not strike the screen in the same spot as the main beam. There is no sense in placing the diaphragm at the input end of the focusing anode because the beam there is already narrow. Therefore the best place for the diaphragm is about half-way along the focusing anode.

Screening between the pairs of deflectors

Besides the mechanical and electron-optical improvements the tube DG 7-3 incorporates another new feature of an entirely different nature, a screening between the two pairs of deflecting plates. This circumvents the trouble, occurring especially at high frequencies, of a voltage on one pair of plates tending to generate a voltage on the other

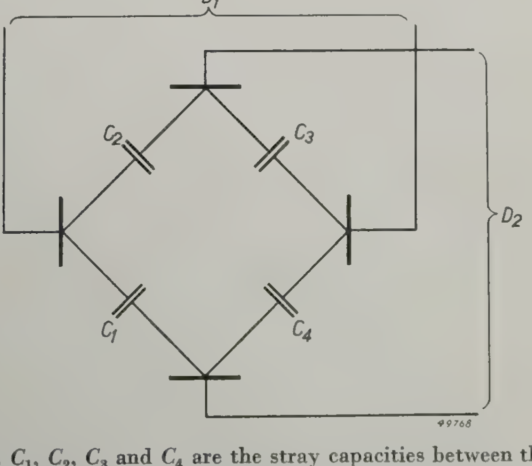


Fig. 6. C_1, C_2, C_3 and C_4 are the stray capacities between the deflecting plates (and their leads) belonging to different pairs. Through these capacities the pairs of plates D_1 and D_2 are apt to exercise an adverse electrical effect upon each other.

4) P. Deserno, Arch. Elektrotechn. **29**, 139-148, 1935.

5) Strictly speaking, one should not take the lens-cathode distance but that from the lens to the smallest diameter of the beam between the cathode and the lens; it is in fact this smallest diameter that is thrown on the screen, but it is so close to the cathode (1-2 mm) that for the sake of simplicity we may roughly speak of the lens-cathode distance.

pair, which of course is undesirable. This effect — sometimes called "cross-talk" in analogy with certain phenomena occurring in telephony — manifests itself in a distortion of the oscillogram, which in the case of a frequency of 100 000 c/s and over may be very troublesome. The cause of this lies in the stray capacities C_1, C_2, C_3, C_4 (*fig. 6*) between the plates (including their leads) which belong to different pairs, or rather in the inequality of those capacities. As may be calculated, the pair of deflectors D_2 would not be affected by D_1 if C_1 were equal to C_2 and C_3 equal to C_4; inversely D_1 would not be affected by D_2 if C_1 were equal to C_4 and C_2 equal to C_3. This effect could, therefore, be neutralised in both directions if the four capacities were made equal with the aid of correcting capacitors, but these are so small (only a few pF) that correction is impracticable. A simpler way is to apply a screening so as to reduce these capacities far enough for the differences to be so small as to render the "cross-talk" imperceptible. That it has been possible to achieve this is due partly to the fact that the capacities between the pins in the flat glass base are so much smaller than those between the lead wires in a pinch with base cap.

The screening referred to consists of two metal partitions, one (*C* in fig. 2*b*) between the two pairs of deflecting plates, with an aperture for the passage of the beam, and another between the two pairs of lead wires. These partitions, clearly to be seen in fig. 1*c*, are connected to the final anode. By these means the capacities have been reduced from a few pF to less than 0.1 pF. Provided also the external leads are properly screened there will no longer be any trouble from mutual effect between the deflectors, not even at very high frequencies.

It goes without saying that the various improvements described here will not be confined to one type of tube but will be applied also in other types where necessary, as is in fact already being done.

ON THE CRYSTALLINE STRUCTURE OF FERRITES AND ANALOGOUS METAL OXIDES

by E. J. W. VERWEY, P. W. HAAYMAN and E. L. HEILMAN†

546.723-3: 548.73

Ferrites are binary oxides, the technically most important type of which is indicated by the general chemical formula MFe_2O_4 (M a bivalent metal). The ferrites of particular importance in electrotechnology are those with a crystal structure analogous to that of the mineral spinel $MgAl_2O_4$. These ferrites form an essential component of the new magnetic material for high frequencies, "Ferroxcube", and also of certain resistance materials which have a large (negative) temperature coefficient of resistance. The magnetic and electrical properties of these ferrites and of the mixed crystals of which they form a part depend very closely upon certain peculiarities of their crystal structure. The latter is described in this article. It is found that the data about the ferrites in question and their mixed crystals with substances of analogous structure can be summarized in three "rules", which considerably facilitate the preparation of materials with certain desired physical properties.

In recent years all kinds of new materials of importance in electrotechnology have been developed in the Philips Laboratories. Among these certain ferrites and the mixed crystals of ferrites occupy a special position. The ferrites are binary oxides with the formula $MFeO_2$ or MFe_2O_4, where M is respectively a monovalent or bivalent metal. In this article we shall deal exclusively with ferrites with bivalent metal. The new magnetic material for high frequencies, "Ferroxcube", is composed of mixed crystals of these ferrites; this material has recently been discussed in detail in this periodical[1]). These ferrites also constitute part of certain mixed crystals which have a practical significance because of their large negative temperature coefficient of resistance. All the ferrites used in "Ferroxcube" and in the resistance materials mentioned have this in common, that they have the same crystal structure, namely that of the mineral spinel $MgAl_2O_4$, which crystallizes in the cubic system. It has become customary to call ferrites and other related oxides having the spinel structure and corresponding to the formula XY_2O_4, where X and Y indicate metals, also spinels. We shall often use that term in this article and in that way avoid the confusion which might arise from the term "ferrites", because of the fact that ferrites with bivalent metal are also known, which have a different structure.

Since the magnetic and electrical properties of spinels are very closely connected with the position of the metal ions in the crystal lattice, it was desirable to study the spinel structure in detail. The results of this crystallographic investigation will be discussed in this article; in a subsequent article we shall return to the electrical properties of the spinels and their employment as resistance materials (their magnetic properties were the subject of the article already referred to).

[1]) Philips Techn. Rev. 8, 359, 1946.

The spinel lattice

The structure of an ideal crystal lattice is completely given as soon as the arrangement of the atoms in the so-called elementary cell is known. The elementary cell is the smallest structural unit and in the most general case it is a parallelopiped. By placing such parallelopipeds side by side and piling them on top of each other in such a way that corresponding edges are parallel, the whole crystal is obtained.

From X-ray analysis the following is now known about the structure of an elementary cell of the spinel lattice.

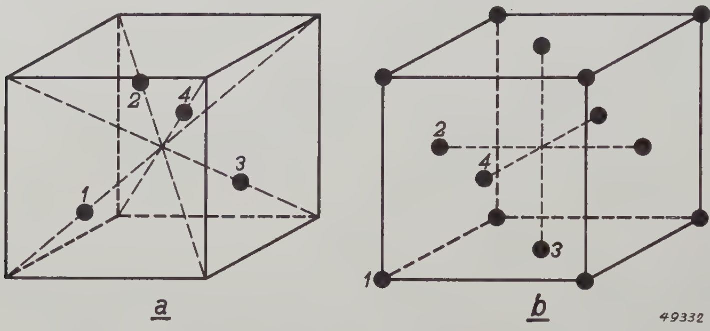
The elementary cell is a cube containing 8 molecules of XY_2O_4, *i.e.* a total of 56 atoms. Due to the presence of such a large number of atoms per elementary cell, its structure is quite complicated. We shall first concern ourselves with the position of the oxygen ions and then with that of the metal ions [2]).

Let us imagine for the time being that all the metal ions are removed from the spinel lattice. The lattice of the remaining oxygen ions is then relatively simple. The elementary cell of this oxygen ion lattice is then found to be twice as small linearly as that

[2]) For the sake of convenience we speak here of oxygen ions and metal ions. This does not mean, however, that we wish to imply that one is concerned with a pure ionic binding in the spinel lattice.

of the spinel lattice, so that it contains only four oxygen atoms. In other words, if the elementary cube of the spinel lattice is divided into eight equal cubes — which we shall call "octants" — these eight "octants" are absolutely identical as far as position of the oxygen ions is concerned.

The position of the four oxygen ions in an octant is now such that on each body diagonal of the octant there is one oxygen atom, as represented in *fig. 1a*; the distance of the ion to the closest corner point of the octant is the same for all four ions and amounts to 1/4 of the length of the diagonal.



Figs. 1 *a*) anb *b*): Two possible choices of the elementary cell of the oxygen ion lattice in spinels. The large black dots indicate oxygen ions. *b*) is formed from *a*) by shifting all the lattice points parallel to the body diagonal on which oxygen ion *1* is siuated.

The centres of the oxygen ions in this oxygen ion lattice have the same spatial arrangement as the centres of a packing of spheres with a cubic symmetry where the empty space between the spheres is as small as possible, *i.e.* the so-called closest cubic packing of spheres.

Whether the oxygen ions in the spinels "touch" each other like the spheres in the cubic packing depends, of course, on the size of the metal ions which must be situated between the oxygen ions. Now in general the metal ions are considerably smaller than the oxygen ions. Therefore they can be placed in the interstices between the cubic packing of the oxygen ions without causing it to "swell" too much. Thus the oxygen ions nearly touch each other.

It should be mentioned here that actually the oxygen ion lattice of the spinels deviates somewhat from the arrangement of the closest cubic packing of spheres. The deviations are due to the fact that the metal ions do not push aside the oxygen ions directly surrounding them everywhere in the same way. These displacements, however, take place in such a way that the cubical symmetry is retained.

We shall now discuss the position of the metal ions in the interstices between the oxygen ions. There are two kinds of interstices:

Firstly, the interstices surrounded by four oxygen ions forming a tetrahedron; these interstices may be called tetrahedron spaces. Secondly, the interstices surrounded by six oxygen ions forming an octahedron and consequently called octahedron spaces. The tetrahedron and octahedron spaces are given in figs. *2a* and *b* respectively. The arrangement of the tetrahedra and octahedra can be made somewhat clearer by choosing the elementary cell of the oxygen ion lattice differently. If one imagines all the lattice points to be displaced in the direction of a body diagonal in such a way that the oxygen ion indicated as *1* in fig. 1*a* lies at the lower left-hand corner, the elementary cell shown in fig. 1*b* is obtained. In the same way figs. 2*a* and *b* then become figs. 2*c* and *d*. By reference to these figures it may be seen that per elementary cell of the oxygen ion lattice (*i.e.* per octant of the elementary cell of the spinel lattice) there are 4 octahedron spaces and 8 tetrahedron spaces. Thus per elementary cell of the spinel lattice we have at our disposal 96 spaces.

Which of the 96 spaces are occupied by the 24 metal ions?

As far as the position of the metal ions is concerned the 8 octants of an elementary cell are found to fall into two groups of 4 octants, in such a way that the 4 octants of the same sort always have one edge in common (see *fig. 3*). In the octants of one sort only the 4 octahedron spaces are occupied (*cf.* fig. 2*f*); in the octants of the other sort all the octahedron spaces are unoccupied and only two of the tetrahedron spaces are occupied, as indicated in fig. 2*e*.

Fig. 4 shows the arrangement of the oxygen ions as well as of the metal ions in the elementary cell of the mineral spinel $MgAl_2O_4$. The illustration gives somewhat more information than follows from the above. So far we have been concerned with the position of the metal ions without

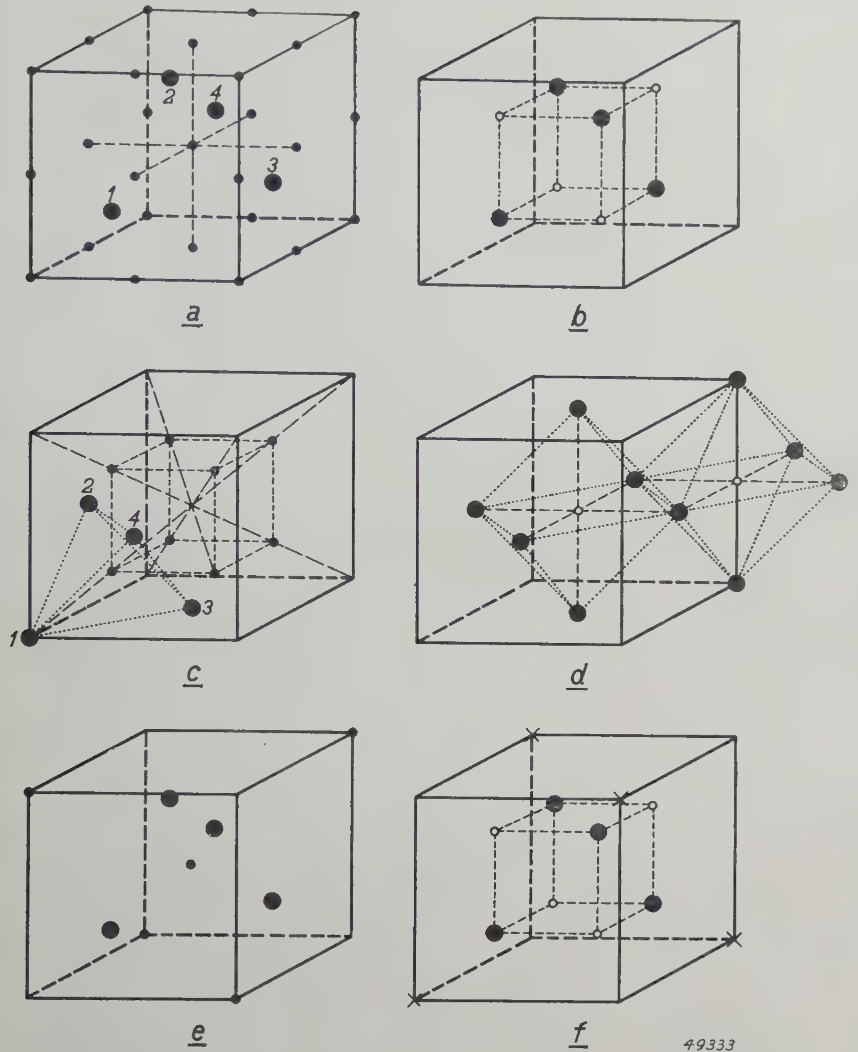


Fig. 2*a*) anb *b*): Position of the centres of the tetrahedron spaces (small black dots) and octahedron spaces (small circles) in the elementary cell of the oxygen ion lattice chosen according to fig. *1a*. *c*) and *d*): The same as in *a*) and *b*) when the elementary cell is chosen according to fig. 1*b*), in other words *c*) and *d*) are formed from *a*) and *b*) respectively by the shifting of all lattice points parallel to the body diagonal on which the oxygen ion *1* is situated. For the sake of clarity in *c*) and *d*) all the oxygen ions and the centres of all the octahedra are not indicated. *e*) and *f*) are formed from *a*) and *b*), respectively, by the omission of the centres of all those tetrahedra and octahedra which are not occupied by the metal ions; in *f*) moreover, we have indicated with crosses the centres of those occupied tetrehadra which in the text are considered as belonging to the octants of the other sort.

taking into account the fact that there are two kinds of metal ions present in every spinel, while in the illustration the positions of the two kinds of metal ions are indicated separately. We shall now discuss this latter point.

The distribution of the different metal ions among the available spaces

The general chemical formula XY_2O_4 is satisfied not only by the spinels which are built up of one bivalent and two trivalent metal ions (per "molecule") (for example $MgAl_2O_4$), but also by the spinels which are built up of one tetravalent and two bivalent metal ions (per "molecule") (for instance Mg_2TiO_4). We shall devote our attention to the first-mentioned possibility. Analogous considerations hold for the other case.

We have seen that in the spinel structure 8 tetrahedron spaces and 16 octahedron spaces, whose position in the elementary cell was indicated, are occupied by metal ions. In the following these 24 spaces will be indicated as those "available" for the metal ions. How are the bivalent and trivalent metal ions now distributed among the available spaces? (As already stated, the answer to this question is of great importance for predetermining the physical properties of the spinels.)

At first this was not considered to be any problem at all, the 8 bivalent ions being located — it was thought — in the 8 available tretahedron spaces and the 16 trivalent ions in the 16 available octahedron spaces. In many cases this is indeed true; spinel proper, $MgAl_2O_4$, may serve as an example of this (*cf.* fig. 4).

Barth and Posnjak[4]), however, pointed out that this simple assumption is by no means correct in every case. By studying X-ray diffraction photographs of a number of spinels in which the two

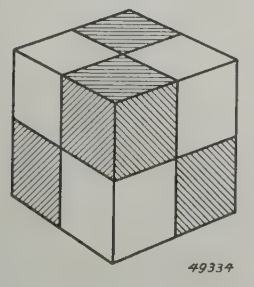


Fig. 3. The cube represents symbolically the elementary cell of the spinel lattice. The four shaded and the four non-shaded octants are occupied respectively in the same way by the metal ions, namely as in figs. 2*e*) and 2*f*) respectively.

[3]) In Fig. 2*e* the centre of the cube and four corners are indicated as occupied by metal ions. It must not be forgotten, however, that each of the occupied corners must be considered as belonging to four similar octants, so that only 1/4 of it belongs to the figure in question. There are therefore, as claimed in the text, $1 + 4 \times {}^1/_4 = 2$ occupied tetrahedron spaces per octant.

[4]) T. F. W. Barth and E. Posnjak, Z. Kristallogr. **82**, 325, 1932.

kinds of metal ions have a sufficiently large difference in scattering power for X-rays, they were able to show that there are also spinels with the 8 bivalent ions in 8 of the 16 available octahedron spaces and with the 16 trivalent ions distributed equally over the remaining 8 available octahedron spaces and the 8 tetrahedron spaces. The 8 bivalent and 8 trivalent ions are at the same time distributed at random among the 16 octahedron spaces in question. In other words in the available octahedron spaces of an elementary cell one finds only on an average equal numbers of bivalent and trivalent ions. This also means that the concept of "elementary cell" has here lost its significance as far as the metal ions are concerned.

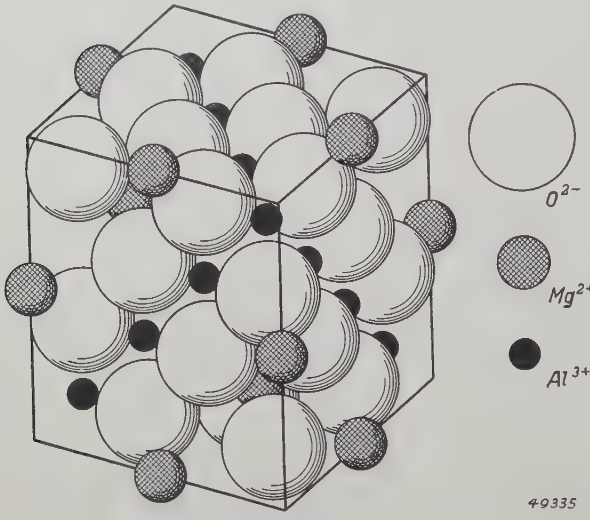


Fig. 4. Elementary cell of spinel proper, $MgAlO_{24}$. It may be seen that the oxygen ions are much larger than the metal ions.

The electrostatically most stable configuration of a spinel lattice

When it is seen that in some spinels the equally charged metal ions are situated only in the octahedron spaces and in others over octahedron and tetrahedron spaces, the question arises as to how this distribution is determined.

It might be assumed that it depends upon the size of the ions, so that for example the smallest ions will occur as far as possible in the tetrahedron spaces, which are considerably smaller than the octahedron spaces; but this is contrary to what has been observed.

Another factor which may determine the distribution of the metal ions among the available spaces is the electrostatic energy of the spinel lattice (in the following called "lattice energy"), *i.e.* the energy gained when the ions, first considered to be at an infinite distance from each other, are joined to form the spinel lattice. Because if the chemical binding in a spinel lattice is brought about only by the electrostatic (Coulomb) forces (attraction between ions of the same sign), that distribution of metal ions will be most stable where the lattice energy is greatest. In order to judge whether this is actually the case we have calculated the lattice energy for several possible distributions of metal ions. The results of these calculations are given below; the comparison with the observations will be dealt with in the following paragraph.

We consider spinels *A*), built up of bivalent and trivalent metal ions ,and *B*) built up of bivalent and tetravalant metal ions. In case (*A*) as well as in case (*B*) there are two possibilities. In case (*A*):

Aa) The bivalent ions are situated only in the tetrahedron spaces and the trivalent ions only in the octahedron spaces. The lattice energy E per molecule of XY_2O_4 then amounts to

$$E_{Aa} = 150.3 \, \frac{e^2}{a} \text{ erg},$$

where e is the charge of the electron in e.s.u. and a is the lattice constant in cm, *i.e.* the length of the edge of the elementary cell.

Ab) The bivalent ions are situated only in the octahedron spaces and the trivalent ions are distributed equally over the octahedron and tetrahedron spaces:

$$E_{Ab} = 143.6 \, \frac{e^2}{a}.$$

In case (*B*):

Ba) The tetravalent ions are situated only in the tetrahedron spaces and the bivalent ions only in the octahedron spaces:

$$E_{Ba} = 142.1 \, \frac{e^2}{a}.$$

Bb) The tetravalent ions are situated only in the octahedron spaces and the bivalent ions are distributed equally over octahedron and tetrahedron spaces:

$$E_{Bb} = 150.3 \, \frac{e^2}{a}.$$

As to the calculations which led to these results, the following should be noted. In case (*Aa*) we obtain the same value for the lattice energy as in case (*Bb*) due to the fact that in the latter case, in which the bivalent and tetravalent ions occur

in equal numbers distributed at random in the octahedron spaces, we assumed that electrostatically this presents the same picture as a distribution of trivalent ions whose number is equal to that of the sum of the bivalent and tetravalent ions. In a similar way in the calculation in case (*Ab*), where the bivalent and trivalent ions occur in the octahedron spaces, we have considered them as 2 1/2 valent ions.

A comparison of the calculated values of the lattice energy now shows that the most stable state of a spinel lattice built up of bivalent and trivalent metal ions corresponds to case (*Aa*), where the trivalent ions are located exclusively in the octahedron spaces. On the other hand for a spinel lattice built up of bivalent and tetravalent metal ions the most stable state is found to be that where the bivalent and tetravalent ions are distributed over the octahedron spaces (case *Bb*). This conclusion is valid only when the lattice constant *a* in cases (*Aa*) and *Ab*) (and in cases (*Ba*) and (*Bb*), respectively, has about the same value, which is quite plausible.

The fact that cases (*Aa*) and (*Bb*) must correspond to the electrostatically most stable states can also easily be understood qualitatively. It will be advantageous from the point of view of energy if the most highly charged metal ion is surrounded by as many negatively charged oxygen ions as possible. And that is exactly true in cases (*Aa*) and (*Bb*).

Checking against observations

In order to compare the above theoretical results with the actual facts we determined by X-ray analysis the distribution of the metal ions in a large number of spinels. The data thus obtained combined with those already known from the investigations of Barth and Posnjak lead to the following conclusions.

For aluminates MAl_2O_4 and chromites MCr_2O_4 (M bivalent metal), where the metal ions are bivalent and trivalent, as well as for the titanates MTi_2O_4 and the stannates M_2SnO_4 (M bivalent metal), where the metal ions are bivalent and tetravalent, the actual distribution of the metal ions over the available spaces is in agreement with our calculation on the basis of the electrostatic lattice theory.

As far as the ferrites are concerned the situation is not so simple.

In $ZnFe_2O_4$ and $CdFe_2O_4$ the distribution of metal ions corresponds to the electrostatic theory; in $MgFe_2O_4$ and $CuFe_2O_4$, on the other hand, it does not: here the trivalent ions (ferric ions) are divided among octahedron and tetrahedron spaces. In the other ferrites with spinel structure, for example $CoFe_2O_4$, $MnFe_2O_4$ and Fe_3O_4, the difference in scattering power between the bivalent and trivalent metal ions is too small to make it possible to draw any conclusions about the location of the ions from the relative intensities of the X-ray reflections. Some conclusions may, however, be drawn in this respect if we compare the values of the lattice constant for different aluminates and ferrites with each other.

Table I.

Columns (2), (4) and (6) give respectively the values (in Å) of the lattice constant for different aluminates, chromites and ferrites, columns(3) and (5) the differences between these values for the corresponding chromites and aluminates and for the ferrites and chromites respectively. The values in column (1) are the radii (also in Å) of the bivalent metal ions. The radii of the trivalent ions are given under their chemical symbols. Cu chromite and Cd aluminate with spinel structure are unknown, The value of the lattice constant of Mn ferrite is uncertain. The figures published for the radius of the Cu^{2+} ion are contradictory and this value is therefore not given here.

(1)		(2)	(3)	(4)	(5)	(6)
		Al^{3+} 0.57		Cr^{3+} 0.64		Fe^{3+} 0.67
Ni^{2+}	0.78	8.05	0.25	8.30	0.06	8.36
Cu^{2+}		8.07	—	—	—	8.37
Mg^{2+}	0.78	8.07	0.24	8.31	0.05	8.36
Co^{2+}	0.82	8.08	0.24	8.32	0.04	8.36
Zn^{2+}	0.83	8.07	0.23	8.30	0.12	8.42
Fe^{2+}	0.83	8.12	0.22	8.34	0.05	8.39
Mn^{2+}	0.91	8.26	0.23	8.49	0.06?	8.55?
Cd^{2+}	0.97	—	—	8.57	0.12	8.69

In *table I* the values are given of the lattice constant for different aluminates, chromites and ferrites. Upon passing from an aluminate to the corresponding chromite the lattice constant increases, in agreement with the fact that the radius of the Cr^{3+} ion is larger than that of the Al^{3+} ion. For all pairs of corresponding chromites and aluminates this increase is approximately equal to 0.24 Å. Since the difference between the radius of the Fe^{3+} ion and that of the Cr^{3+} ion is about one half the difference between the radius of the Cr^{3+} ion and that of the Al^{3+} ion, it might be expected that the increase in the lattice constant upon passing from a chromite to the corresponding ferrite would be about 0.24 : 2 = 0.12 Å. This is indeed true in the case of Zu and Cd ferrite, *i.e.* for the ferrites for which the distribution of the metal ions corresponds to the electrostatic theory. For all other ferrites, however, a remark-

able fact is observed: the increase of the lattice constant is much smaller, and for all of them about equal to 0.05 Å.

Now among the ferrites which, as far as the lattice constant is concerned, show a deviating but mutually similar behaviour belong Mg and Cu ferrite, where the ferric ions are divided among the tetrahedron and octahedron spaces. From this we feel justified in concluding that the distribution of the metal ions in Co, Mu and Fe^{2+} ferrites is the same as in Mg and Cu ferrite, *i.e.* that the ferric ions in all these ferrites are also distributed among the tetrahedron and octahedron spaces.

There are other no less important arguments for the correctness of this conclusion.

One argument, for example, is furnished by the fact that all these ferrites are ferromagnetic with the exception of Zn and Cd ferrite. This question is briefly discussed in the article referred to in footnote [1]); we shall not go into it here. Another argument can be deduced from a consideration of the conductivity of the mixed crystals of ferrites, to which we shall revert in a subsequent article.

As a conclusion to the discussion of the probable distribution of the metal ions among the available spaces we should like to mention the following. The excellent agreement between the purely electrostatic theory of the spinel lattice and experiment in the case of aluminates, chromites and Zn and Cd ferrites need not suggest that the chemical binding of these spinels is almost purely electrostatic, although electrostatic forces undoubtedly play an important part. There are many indications that the binding in the spinels cannot be entirely approximated by the electrostatic conception of chemical valence and that homopolar forces (*i.e.* atomic binding in contrast to ionic binding) makes a significant contribution to the total picture of the binding forces. The explanation of the fact that the ferrites do not all behave in the same way, as far as the distribution of the metal ions is concerned, must be sought in certain finesses connected with these non-electrostatic forces. We shall not go further into it here because the theory is not yet able to explain the phenomenon satisfactorily.

Rules for the distribution of metal ions in spinels

On the basis of the results discussed above we may now set out the following rules for the structure of spinels built up of bivalent and trivalent or bivalent and tetravalent metal ions.

1) The trivalent and tetravalent metal ions occupy the octahedron spaces in agreement with the electrostatic conception of the structure of spinels.
2) Exceptions are the Fe^{3+} ions, which have a preference for the tetrahedron spaces. In^{3+}- and Ga^{3+}-ions, which have not been mentioned in this article, are also exceptions to rule (1).
3) Zn^{2+} and Cd^{2+} have a strong preference for the tetrahedron spaces and are able to drive the ions mentioned under (2) out of these spaces.

From the measurements of intensity on X-ray diffraction photographs we were able to deduce that these rules also remain valid for the formation of mixed crystals of the spinels. Several examples are given in *table II*.

Although we were unsuccessful in completely solving the problem of the structure of the spinels theoretically — the preference of Fe^{3+} ions for the tetrahedron spaces remains somewhat mysterious — the investigation has had the result that with the help of the above-formulated rules we can predict the position of the metal ions in any arbitrary mixed crystal with very great probability, and we can therefore also prepare materials with a desired ion distribution. As will appear from a following article, this has not unimportant practical consequences.

Table II.

Structure of the mixed crystals of two spinels with the components taken in a mol ratio of 1 : 1. The symbols of the ions situated in the octahedron spaces are placed between parentheses. Roman numerals indicate the valence of the iron ions.

Components of the mixed crystal			Structure of the mixed crystal
$Fe^{III}(Fe^{II}, Fe^{III})O_4$	and	$Fe^{II}(Al, Al)O_4$	$Fe^{III}(Fe^{II}Al)O_4$
$Fe^{III}(Cu, Fe^{III})O_4$	and	$Zn(Fe^{III}, Fe^{III})O_4$	$Zn_{0,5}Fe^{III}_{0,5}(Fe^{III}_{1,5}, Cu_{0,5})O_4$
$Zn(Fe^{III}, Fe^{III})O_4$	and	$Zn(Cr, Cr)O_4$	$Zn(Fe^{III}, Cr)O_4$
$Zn(Ti, Zn)O_4$	and	$Fe^{III}(Mg, Fe^{III})O_4$	$Zn(Fe^{III}, Mg_{0,5}, Ti_{0,5})O_4$
$Mg(Ti, Mg)O_4$	and	$Fe^{III}(Mg, Fe^{III})O_4$	$Fe^{III}(Ti_{0,5}, Mg_{1,5})O_4$
$Zn(Fe^{III}, Fe^{III})O_4$	and	$Fe^{III}(Fe^{III}_{1,67})O_4$	$Zn_{0,5}Fe^{III}_{0,5}(Fe^{III}_{1,83})O_4$

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of the majority of these papers can be obtained on application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands. Those papers of which no reprints are available in sufficient number are marked with an asterisk.

1722: H. J. Lindenhovius: Het meten van impedanties bij hoge frequenties en toepassingen van de staande golfindicator (T. Ned. Radiogen. **12**, 60-82, 1947). (The measurement of impedance at h.f. and applications of the standing wave indicator).

In this article a survey is given of the different methods used in measuring impedances.

For frequencies below about 300 Mc/s the method used most frequently is that which employs a tuned circuit and in which the impedance is determined from its damping and detuning influence on the circuit.

For higher frequencies the lumped circuit can be replaced by a tuned transmission line but in that case some difficulties arise and it is preferable to use an untuned transmission line and to determine the impedance from the voltage distribution along the line.

The voltage distribution is characterised by the standing wave ratio and the position of the voltage minimum. A new diagram has been designed, which enables one to determine the impedance graphically and in a most comprehensible way even for very large values of the standing wave ratio. In connection with the measurement of the voltage distribution the standing-wave indicator is described.

Finally a number of other applications of the standing-wave indicator are dealt with, such as the measurement of characteristic impedance and attenuation constant of a transmission line and the measurement of net power flow along a transmission line.

1723: P. Cornelius: Eén eenhedenstelsel in de electriciteitsleer (Faraday **16**, 57-67, 1947). (One system of units in electro-magnetic theory).

A short survey is given of the basic formulae of electromagnetism using rationalized Giorgi units (M.K.S. units). The didactic value of using these units is stressed.

1724: J. L. Snoek: Zeitabhängige Erscheinungen in Eisen enthaltenden Stoffen unter dem Einfluss mechanischer und magnetischer Kräfte (Schweizer Archif angew. Wiss. und Techn. **13**, 9-14, 1947).

For the contents of this paper the reader is referred to the article by J. L. Snoek and K. F. du Pré, Philips Techn. Rev. **8**, 57, 1946 and to the book: J. L. Snoek, New developments in ferromagnetic materials, Amsterdam 1947 (see abstract No. 1729).

1725: J. H. van Santen and G. H. Jonker: Effect of temperature on the permittivity of Barium Titanate (Nature **159**, 333, 1947).

Above a certain transition temperature (ϑ) crystals of barium titanate $BaTiO_3$ and related compounds, such as $SrTiO_3$, (Ba, Sr) TiO_3 and TiO_2, show a cubic structure. At the temperature ϑ the permittivity has a sharp maximum. It decreases monotonically with increasing temperature. This decrease is explained from the Clausius-Mosotti formula. Taking into account the thermal expansion and ignoring the temperature dependence of the polarisability, it follows that for higher values of ε

$$\frac{1}{\varepsilon} = \beta \,(\mathrm{T} - \mathrm{C}).$$

With the titanates the polarisability proves to be independent of the temperature. Then β is the coefficient of thermal expansion.

It is believed that in the cubic region ($T < \vartheta$) there is no permanent dipole moment, whereas in the tetragonal region ($T < \vartheta$) the assumption of dipoles seems to be quite plausible.

1726: M. Gevers: The relation between the power factor and the temperature coefficient of the dielectric constant of solid dielectrics (Thesis, Delft, 1947).

In this thesis the relation between the power factor (tan δ) and the temperature coefficient of the dielectric constant of solid, amorphous dielectrics is dealt with theoretically as well as experimentally. This subject has already been treated in a paper by M. Gevers and K. F. Du Pré (Philips Techn. Rev. **9**, 91, 1947). The methods of measurement are described and a number of special cases are dealt with. Finally some remarks are made on the properties of mixtures of dielectrics. (Also published

in Philips Res. Rep. **1**, 197, 279, 361, 447, 1946, R 15, 20, 25, 30.)

1727: J. F. H. Custers: On the relation between deformation and recrystallization texture of nickel-iron with cubic orientation (Physica **13**, 97-116, 1947).

Polycrystalline nickel-iron ($\sim$ 50 weight % Ni) which has been severely cold rolled exhibits on recrystallisation at about 1000 °C a so-called cubic orientation. Aluminium does not show this texture upon recrystallisation. To trace any difference in slip mechanism between Ni-Fe and Al, the deformation and recrystallisation textures of polycrystalline Ni-Fe with cubic orientation were investigated and the findings were compared with observations of Burgers and Louwerse on single crystals of Al. On the whole the deformation textures were found to be the same. There are, however, marked differences due to the Ni-Fe specimen being not a mono-crystal. The recrystallisation textures are strongly different. The reason is to be found in the difference between the deformation textures. This can be explained by Burgers' theory. The second part contains a discussion of Barrett's criticism of this theory.

1728: J. M. Stevels: The effective permittivity of compressed and sintered samples of TiO_2 Rec. Trav. chim. Pays-Bas **66**, 71-74, 1947.

The effective permeability of compressed and sintered samples of TiO_2 has been measured and the results are discussed in terms of the theory developed by Polder and van Santen (abstract 1698). The experimental curves show that in loose powders the holes are more or less disc-shaped. The more the samples are sintered the more nearly spherical the holes become.
As a whole the results confirm the theory mentioned.

Number 4 of Volume 2, August, 1947 of *Philips Research Reports* contains the following papers:

R 49: F. L. H. M. Stumpers: On a non-linear noise problem.

R 50: J. L. Meyering and M. J. Druyvesteyn: Hardening of metals by internal oxidation, part II.

R 51: T. H. Oddie and J. L. Salpeter: Minimum cost chokes.

R 52: A. J. Dekkers and W. Ch. van Geel: On the amorphous and crystalline oxide layer of aluminium.

Readers interested in any of the above mentioned articles may apply to the Administration of the Philips Physical Laboratory, Kastanjelaan, Eindhoven, Holland, where a limited number of copies are available for distribution.
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